

Advancing Automation and Robotics Technology for the Space Station Freedom and for the U.S. Economy

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Progress Report 9 - March 1989 Through July 1989

**Advanced Technology Advisory Committee
National Aeronautics and Space Administration**

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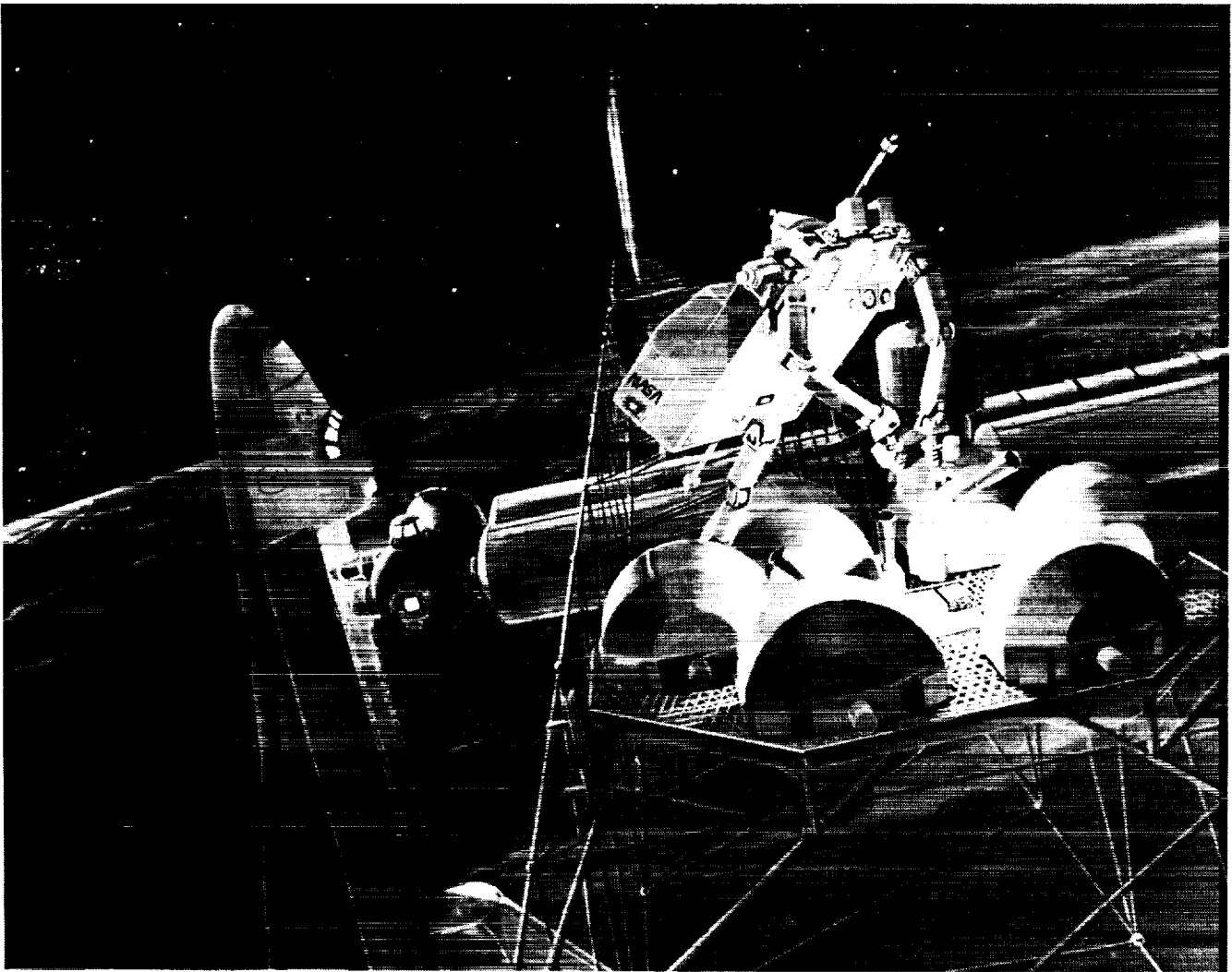


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CONTENTS

Introduction	2
ATAC Assessments	4
ATAC Recommendations	13
Appendix A: OSS A&R Progress	14
Appendix B: Flight Telerobotic Servicer Progress	21
Appendix C: References	32
Appendix D: Acronyms	33
Appendix E: NASA Advanced Technology Advisory Committee	35



Flight Telerobotic Servicer (FTS)

The Flight Telerobotic Servicer (FTS) is being developed for Space Station Freedom by NASA and the Martin Marietta Astronautics Group. It will have a pair of force-reflecting 7 degree-of-freedom manipulators, a stabilizing and positioning system, cameras, lights, and end-of-arm tooling.

From workstations inside either the NSTS Shuttle or the Station, the FTS will be capable of both teleoperation and automated control. It will be able to assist in assembling and servicing the Station as early as first element launch. With the FTS augmenting the astronauts, operation of the Space Station Freedom will be more productive.

INTRODUCTION

Background

In response to the mandate of Congress, NASA established, in 1984, the Advanced Technology Advisory Committee (ATAC) to prepare a report identifying specific Space Station Freedom systems which advance automation and robotics (A & R) technologies. In March 1985, as required by Public Law 98-371, ATAC reported to Congress the results of its studies (ref. 1). The first ATAC report proposed goals for automation and robotics applications for the initial and evolutionary space station. Additionally, ATAC provided recommendations to guide the implementation of automation and robotics in the Space Station Freedom program.

A further requirement was that ATAC follow NASA's progress in this area and report to Congress semiannually. In this context ATAC's mission is considered to be the following:

Independently review the conduct of the Space Station Freedom program to assess the application of A & R technology with consideration for safety, reliability, schedule, performance, and cost effectiveness (including life-cycle costs). Based upon these assessments, develop recommendations to enhance A & R technology application, review the recommendations and discuss their implementation with NASA management. Report assessments and recommendations twice annually to Congress.

The Space Station Freedom program (SSFP) is charged to develop a baseline station configuration which provides an initial operational capability and which, in addition, can be evolved readily to support a range of future mission scenarios in keeping with the needs of space station users and the long-term goals of U.S. space policy.

ATAC has continued to monitor and to report semiannually NASA's progress in the use of automation and robotics in achieving this goal. The reports are documented in the ATAC Progress Reports 1 through 8 (refs. 2-9). Progress Reports 1 through 5 covered the definition and preliminary design phase (phase B) of the Space Station Freedom (SSF). Progress Reports 6 through 8 covered the start up of the design and development phase (phase C/D) of the SSF. Phase C/D leads to a permanently inhabited station, to be operational in the mid-1990's.

This report is the ninth in the series of progress updates and covers the period of February 24, 1989 through July 12, 1989.

To provide a useful, concise report format, all of the committee's assessments have been included in the section "ATAC Assessments." This section of the report includes comments on SSFP's progress in responding to the ATAC recommendations in Report 8. Also, summaries of progress in A & R in the NASA Office of Space Station (OSS) and the Flight Telerobotic Servicer (FTS) are provided as appendices as written by those offices, respectively. The report draws upon individual ATAC members' understanding and assessments of the application of A & R in the SSFP and upon material presented during an ATAC meeting, held July 11-12, 1989, for the purposes of reviewing SSFP A & R activities and formulating the points of the assessment.

Climate

The Space Station Freedom Program has been through a difficult time during this reporting period. The budget continues to pose problems for the program. Also, a number of circumstances, including the enactment of new legislation which limits post-government employment opportunities

of government officials, have led many top level NASA employees to leave the civil service. The SSFP was affected by this very high turnover. During the reporting period for this ATAC report, the Associate Administrator for Space Station, who enthusiastically advocated the implementation and use of A & R technologies in the SSFP, the Deputy Associate Administrator, and the Program Director all resigned. In addition, some organizational changes took place. It is in this context that ATAC reviews SSFP A & R activities.

In this climate it has been very difficult to maintain a consistent, positive approach to implementing A & R policy throughout the SSFP. In particular, as a result of the leadership and organizational changes, the SSFP has not been able to make much progress in implementing the specific recommendations contained in ATAC Report 8. ATAC does note, however, that even in the face of adverse circumstances good results have been obtained in some areas of A & R. The FTS contractor was selected and has made impressive progress in the final design of the FTS and flight test plans. The SSFP Level I Advanced Development Program

fostered good technical accomplishments and has helped to increase the awareness of potential A & R contributions throughout the program. Level II personnel have made substantial efforts to start new prototyping programs and have design standards accepted. They will soon complete implementation plans. Unfortunately, management has not always been able to support these efforts. Level III has cooperated with both Levels I and II by submitting proposals for A & R work both within and outside the baseline program and by participating in the Advanced Development Program. All SSFP organization levels have been responsive to ATAC in its effort to perform this period's evaluation.

Nevertheless, despite all of the above-mentioned efforts, the status of A & R (especially advanced automation) on Space Station Freedom is not good. Other than the FTS and a very small number of expert systems (ATAC has only been able to specifically identify two expert systems), there is little A & R in the baseline program and the likelihood of smooth growth and evolution of A & R is problematical.

ATAC ASSESSMENTS

The ATAC assessments for this reporting period are based upon the committee's appraisals of progress in advanced automation and robotics for Space Station Freedom. A review of the progress toward the recommendations from ATAC's most recent report, Progress Report 8, will be discussed first, followed by a review of current activities.

Status of ATAC Progress Report 8 Recommendations

ATAC Progress Report 8 recommendation I was as follows:

(I.) "Complete the A & R Program Plan at all levels within six months, realizing that the plan may change in the future. The plan should explain the A & R goals and organization, and should indicate resources and priorities required to complete implementation of the planned A & R activities. Without this overall plan, there is very little hope for evolution and integration of A & R. Delay in completing the plan reflects a perception of low priority for A & R. (Section 3.7 of the PDR states that such a plan is to be developed.)"

According to Level I, the final draft of the Level I A & R Plan is to be completed by August 31, 1989. This plan will be integrated closely with the Level II A & R Implementation Plan, which is scheduled to be published by September 15, 1989.

As discussed in ATAC Progress Report 8, these documents are needed to clarify and specify the roles and responsibilities of the various focal points in implementing the stated SSFP A & R policy. This policy is to encourage the use of A & R where it is technically appropriate, where

the technology is sufficiently mature, and where there is a favorable benefit-to-cost ratio (ref. 8). ATAC is pleased that the SSFP has adopted this policy, which embodies the intentions of the original ATAC recommendations (ref. 1). However, the implementation of this policy would be facilitated greatly if the planning documents were in existence to serve as guidelines for the implementors.

In summary, even though some progress has been made in producing A & R planning documents, they are not yet released. **ATAC repeats its previous recommendation concerning the A & R Program Plans and urges the SSFP to approve and release these documents as official program requirements by January 1990. As stated in ATAC Progress Report 8, "These planning documents need to be brought to completion in the near future (even if they must be updated later) so they can be used as a basis for decisions in the program. Delay in completing versions of these plans could erode the necessary commitment of A & R in development and operation of the Space Station Freedom.**

ATAC Progress Report 8 recommendations II and III were as follows:

(II.) Establish a hierarchy of the A & R focal points in Levels I, II, and III, and the work package contractors for the purposes of (1) reporting on A & R accomplishments and plans and (2) implementing a high-leverage prototyping activity. While this process has already been initiated by Level II, the process should be formalized in terms of organization and calls for proposals. Consideration should also be given to a higher level of funding for this activity.

(III.) Identified focal points should be kept rigorously current despite changing assignments, and the people identified as focal points not be so burdened with other assignments that promotion of A & R technology becomes an assignment of secondary importance. Moreover, the focal points should be given sufficient visibility into program decisions to assess and advise program management of the impact of the decisions on the applications of A & R.

ATAC noted in Report 8 that the Space Station Freedom Program has a policy which encourages the use of automation and robotics technologies. Despite this policy, ATAC perceives that the organizational lines have not provided for either a direct line of accountability for the implementation of A & R technologies or for transferring results of Level I advanced development activities to Level II and on to the work package contractors. ATAC notes that limited progress has been made in establishing appropriate A & R responsibilities. As part of their normal assignment, each SSFP Distributed Systems Manager, rather than an A & R focal point is now responsible for A & R implementation in their individual area. ATAC applauds this development and feels that it is in concert with the intent of Report 8 recommendations that the decisions to implement A & R capabilities should be made in the line organization. ATAC hopes that having established A & R implementation responsibility, the line organization will actively review actual progress made in implementing specific A & R capabilities.

To provide enhanced identification of potential A & R applications and transfer of these applications to the baseline SSF, ATAC has recommended defining a structure wherein A & R focal points would act to identify and promote high-payoff A & R applications to those with the responsibility for implementation. In particular, ATAC has previously recommended a modification of the existing organizational structure to create a hierarchy of identified Level I, Level II, Level III, and work package focal points with a limited scope of responsibility. These focal points, dedicated only to A & R, would be responsible for implementation of programs or projects that will promote A & R applications and for reporting to ATAC on A & R accomplishments and plans.

Some progress has also been achieved in the area of the A & R focal points. The Level I focal

point, whose assignments and responsibilities appear well defined, has been active in supporting ATAC and A & R activities for some time. Focal points at three of the four NASA Centers with work package responsibility are at present identified and have been active in responding to ATAC requests for advanced A & R activities status reports. However, not all of these focal points have full time A & R responsibility; moreover, they do not have the requisite authority to be effective in fostering the implementation of an A & R program.

The situation of A & R focal points in Level II continues to change. ATAC has been told that there will be two focal points—one for systems engineering and integration (SE & I) and one for operations (previously there were two for SE & I and one for operations). The exact role, organizational location, and authority of these positions was not available to ATAC. ATAC feels that an undesirable situation arises from the continual reassignment of individuals in Level II with responsibility for A & R activities. Frequent reassignment of Level II focal points creates a lack of continuity and detracts from the visibility that these assignees have into important aspects of the program and greatly inhibits their ability to do an adequate job of identifying and recommending advanced A & R technologies for implementation on the baseline Space Station. It is extremely critical that the Level II focal points have adequate visibility in order to advise those with implementation authority as to the various benefits/impacts of decisions to implement A & R activities. ATAC does not view the new focal point assignments as progress in that it is unclear what organizational roles or responsibilities these focal points have or how they relate to either the focal points at the other levels or the line organization managers.

Specific responsibility statements for the focal points at each level should be developed which include hierarchal interrelationships, program overview and visibility responsibilities, methods to access program management and other factors needed to assure that the focal points have sufficient program visibility and management access to assure that A & R is properly considered in the SSFP. Delays and regressions experienced in establishing explicit roles and relationships for the A & R focal points reflect a perception of low priority for A & R development by management.

One responsibility of the A & R focal points, previously suggested by ATAC, could be the implementation of the High-Leverage Prototyping

Program, which was described in ATAC Progress Report 8 (ref. 9). Little activity for this program has taken place in Level II—some proposals were submitted but were not funded. There are plans to resubmit these proposals under a new format but progress is very slow and no funding has been set aside for this program. (See appendix A for more information.) ATAC notes that some elements of the Level I Advanced Development Program have evolved into high-leverage prototyping activities and will continue as such in the immediate future. Nevertheless, ATAC feels that more activities of this type should take place and that the efforts should be closely coordinated between all SSFP levels. **ATAC recommends that Level II should plan to fund the High-Leverage Prototyping Program and coordinate their activities with the Level I Advanced Development Program. The planning and selection of initial projects should take place immediately to ensure implementation on the baseline Station of A & R technologies with significant potential. ATAC also suggests a more formal and continuing procedure for calls for proposals and evaluation procedures, including defined criteria for selection. ATAC strongly recommends that this High-Leverage Prototyping Program, which will directly benefit the baseline Space Station, be funded at a higher relative priority level and be given more emphasis than is presently the case.**

For the High-Leverage Prototyping Program to be of the desired effectiveness, selection of the initial projects with potential for the baseline station and release of funding should be made immediately. ATAC is of the opinion that some of the initial responses by the contractors to the initial High-Leverage Prototyping program are such that immediate action should be taken to insure their implementation. Because of the time lag between initial project selections, technology development of the projected items, and flight implementation, the initial selection should be made as soon as possible. As of the present time, only two advanced automation projects have been identified/proposed for the baseline space station. Moreover, many original work package A & R proposals, which represented high-leverage prototyping, have been de-emphasized due to funding and other program pressures. **ATAC recommends strongly that additional advanced automation projects be identified and implemented. The original work package A & R proposals and high-leverage prototyping proposals should be**

evaluated against suitable selection criteria and the results reported at the next ATAC meeting. In addition, the advanced development program should emphasize high-leverage prototype developments during the next year to encourage A & R implementations for the baseline station.

ATAC Progress Report 8 recommendation IV was as follows:

(IV.) "Develop criteria for assessing the merits of A & R activities and for prioritizing and choosing high-leverage prototype candidates. This will require studies which include systems engineering and integration, verification and validation, systems operations, and life-cycle cost. Specific attention should be given to evaluating the payoff of A & R activities in reduced overall life-cycle costs and incorporating those advanced A & R activities which provide significant life-cycle cost benefits."

There has been very little progress towards establishing criteria for assessing the merits, for Space Station Freedom, of specific technologies. This situation exists for A & R technologies (including high-leverage prototype candidates) Space Station Freedom Program Directive #22 was issued by Level II on March 28, 1989, stipulating that Design to Life-cycle costs (DTLCC) should be used as a "key design parameter in trade-offs" and that it become program policy. In addition, for the life-cycle cost models that are required, the Directive stipulates that data requirements for use in DTLCC evaluations should be specified. Some progress is being made to develop life-cycle cost models which include A & R elements, but there is no indication of the types or source of data that will be required for running either existing models or those being planned. The results of the DTLCC modelling activities should be instrumental in helping Work Package managers make the key decisions required to ultimately include any technology (either A & R or other technologies) into Space Station Freedom. In addition, studies should be performed, such as systems engineering and integration and operations, which will further support the decision-making process.

ATAC, therefore, reaffirms that the Program Directive #22 be adhered to, in a more aggressive way to develop objective criteria for evaluating all SSFP technologies, including A & R, to assure that A & R

technologies are evaluated on an equal basis. Specific attention should be given to evaluating the payoff of technologies in reducing overall life-cycle costs, and incorporating those advanced A & R activities which provide significant life-cycle cost benefits. Previous inadequate life-cycle cost analyses for A & R technology implementation proposals have had a detrimental effect on incorporating A & R capabilities into the SSFP. These criteria should be coordinated across the Operations, Utilization and SE & I groups at Level II to reach consensus as to the benefits of any A & R proposal.

ATAC Progress Report 8 recommendation V was as follows:

(V.) "The efforts of the FTS Mission Utilization Team to define FTS compatible tasks are commendable, but the process is missing a prime user; JSC should participate, and either endorse the set of tasks used as the design basis or define specific performance requirements for the FTS which would make it effective in accomplishing specific tasks."

The GSFC Mission Utilization Team (MUT) has been evaluating potential FTS assembly, maintenance and servicing tasks through the use of the Task Analysis Methodology Document which they have developed. The prime user, JSC, has been involved in this activity on an informal basis only. This process has identified tasks that contribute to the assembly of the Space Station Freedom and could reduce the amount of crew extra-vehicular activity (EVA) time. However, these initial studies have not fully integrated FTS activities with those of the astronauts.

There are, at this time, too many different assembly sequence definition activities under way instead of a coordinated, formal focused activity. A single integrated activity should be conducted to define the assembly sequence and the FTS should be considered as a real resource and an integral part of the assembly activities. Moreover, additional thought should be given to contingencies or maintenance requirements arising during the assembly sequence.

In summary there has been progress made in defining realistic tasks for the FTS. However, much more emphasis must be given to using the FTS efficiently and effectively in the Space Station Freedom Program. To achieve this goal, the capabilities of

the FTS and the definition of the various tasks for the FTS should evolve together.

ATAC recommends that a unified SSFP approach be developed to define FTS tasks, initially giving special consideration to those involving assembly sequences. The FTS must be considered as a resource during development of EVA activities, both as an integral part of the assembly sequence and as a contingency resource for maintenance activities during assembly sequences. Previous working groups considering FTS and EVA activities have had informal coordination, however, lack of formal recognition and interaction has delayed identification and acceptance of FTS tasks and capabilities.

ATAC Progress Report 8 recommendation VI was as follows:

(VI.) "Continue funding to permit FTS development and laboratory tests. Make flight integration funding available as soon as possible. Start developing DTF-2 experiments and conduct laboratory tests as opportunities to demonstrate robotics technology. Both DTF flight activities should be designed to be pertinent to specific FTS tasks as defined by the work packages and other users and to include relevant technology experiments on a noninterference basis."

ATAC's assessment is that excellent progress has been made during this reporting period. Martin Marietta has been selected as the FTS prime contractor including DTF-1 and DTF-2. Based upon the refreshingly detailed technical briefing given to ATAC by Martin Marietta in Denver, the committee was impressed with the amount and quality of the technical work which had been carried out by the contractor against the specifications. The trade studies and breadboarding aid in controlling program risk and lend confidence that the projected performance will be achieved. The preliminary design of both hardware and software is quite modular, and there are design accommodations to allow evolution in the future. The plan and funding for the FEL capability appear to be adequate. However, the initial FEL capability is quite conservative and projected evolution is not aggressive. (Evolution of the FTS is beyond the scope of the existing FTS contract.) **SSFP must continue to meet FTS funding requirements to maintain the current positive momentum**

in FTS development. DTF activities should be designed to be pertinent to specific FTS tasks as defined by the work packages and other users and to include relevant technology experiments on a noninterference basis.

Recommendation VII from ATAC Progress Report 8 was as follows:

(VII.) "Continue and expand development of the Robotic Systems Integration Standards to include all space station robots and adopt it as a space station applicable document."

ATAC's assessment is that very good progress has been made during this reporting period. The document titled "Robotic Systems and Interface Standards" is currently undergoing revision to incorporate comments received from review of a preliminary version. Progress in this area attests to NASA and Space Station Freedom Office recognition of the desirability of design commonality of the tools and orbital replaceable units (ORUs) for operations by both the crew members and robots working on the Space Station Freedom. ATAC believes there is still much work to be done to make "Robotic Systems and Interface Standards" an applicable document and time is short for the document to have meaningful impact. Further, the ongoing efforts to define standards and design guidelines need to be coordinated and to coalesce with the efforts of the Robotics Working Group.

Current Activities and Progress in A & R

Some of the material in this section has been mentioned in the earlier section describing the status of SSFP's response to ATAC Report 8 recommendations. This material is repeated here to provide a self-contained section on Current Activities and Progress in A & R.

A & R Policy

As described in the earlier section covering SSFP response to ATAC Report 8 recommendations, the status reports given to ATAC by Levels I and II indicate very little progress has been made in clarifying how the A & R policies are being implemented or in the preparation of the A & R planning documents. In fact, there appears to be confusion in the application of A & R policies. What little progress may have been made in Level II since the last ATAC Report, if any, appears to have been overwhelmed by the proposed organizational changes and the A & R funding cuts.

ATAC's assessment is that the commitment of management at the top levels of the Space Station Freedom program to the application of automation and robotics in program activities is uncertain at this time and management is not encouraging the promotion of an appropriate number of A & R applications. The planning documents have not been completed and do not appear to have sufficient priority to obtain the necessary resources required for completion; funding has been cut for Level II efforts including the rapid prototyping efforts to evaluate, accelerate, and validate the promising technologies prior to implementation; and there appeared to be indications that the FY-90 funding for the Level I A & R program would be deleted. These actions, if left uncorrected, would seriously erode the necessary commitment to A & R in the development and operation of the Space Station Freedom.

It is also ATAC's assessment that there is a discontinuity in the A & R philosophy between the management of Level I and Level II in terms of common goals and implementation strategies and that this difference in philosophy, if continued, will lead to the development of a Station that is manpower-intensive, high in operations costs and maintenance, and not as productive and reliable as it could be. The funding level for the Level II A & R program is almost nonexistent and, if it remains at that level it will not allow the desirable and perhaps necessary incorporation of advanced automation and robotics into either the baseline Station or the evolutionary Station.

A & R Organization and Responsibilities

The following organizational changes have been made in Level II respective to A & R responsibilities: The Deputy Director, Space Station Freedom Program and Operations Office, has designated the Level II group directors and the Level III project managers as responsible for advocating the use of A & R technologies in accomplishing their responsibilities and will be reviewing their plans and progress in these areas twice a year; the Systems Engineering and Integration Group has consolidated the A & R responsibilities under one focal point; and, the Utilization and Operations Group has elevated the A & R responsibility to a position on the Group Director's staff. Much of the above is positive, however, ATAC's interpretation of the new

A & R organization and structure is that there are now reduced resources allocated to A & R activities since the last ATAC report. The organization seems to be moving in the "right" direction but ATAC perceives very little substance to verify that there is commitment at all levels of management to A & R implementation. Little advanced automation has been baselined for the initial Station and a firm program plan has not been developed or implemented for the incorporation of advanced automation into the evolutionary Station. In addition, there does not appear to be a formal mechanism for the implementation of any A & R resulting from the Level II efforts. Policies are stated but lack target objectives for the evaluation of progress and implementation effectiveness. More time-tagged objectives should be defined on an annual basis and reviewed and evaluated semi-annually by ATAC. It was also observed that there continues to be a discontinuity between the Level I and Level II A & R activities and funding profile.

ATAC's assessment is that the A & R program has been seriously compromised by the recent organizational and policy changes within Levels I and II and very little attention will be given to the implementation of A & R within the baseline station. In addition, it is not clear that the baseline architecture will contain the "hooks and scars" for any future evolutionary A & R applications. Further, it is ATAC's opinion that enhanced coordination occur between Office of Aeronautics and Space Technology's A & R program (which addresses NASA's long term A & R needs as well as providing some direct payoff to SSF) and the SSFP baseline and evolutionary A & R application efforts--this approach will lead to more effective utilization and leveraging of the limited Agency's resources allocated to this technology area.

A & R Activities in Levels I and II

Level I should be commended for its aggressive thrust in A & R applications and the definition and formulation of a comprehensive A & R program. The Advanced Development Program funding has grown from \$1.8M in FY-88 to \$8M in FY-89 with a projected growth to \$17M in FY-90. The Level I Program has elevated the interest in A & R and has attracted the attention of the Work Package contractors to the extent that they are now seriously considering the insertion of specific A & R technology applications.

While the activities supported by the Level I program are worthwhile, it is not clear what overall strategy or criteria were used in selecting the particular activities which were funded. Thus, it is unclear as to what overall goal or top level system capability will be achieved if each of the funded task elements is successful and integrated together into an effective system capability. Moreover, there is some ATAC concern that too many application activities are being funded by Level I in the seven Advanced Development Program Task Areas and that more progress could be achieved if the funding was allocated to a fewer number of proposals. Since Space Station test beds are not uniformly available for rapid prototyping tests, Levels I and II should develop and fund a program which will make the Station test beds more amenable to prototype development and evaluation in an environment representative of the operational environment.

A Crew Productivity Study Report has been initiated to assess and evaluate the benefits of automation based on the results of the Skylab and Spacelab missions. This report is scheduled for completion on September 1, 1989. It is felt that this report will provide a good insight on the life-cycle costs associated with the implementation of A & R technologies.

Work Package Activities in A & R

This section reviews the current A & R activities of the four work packages. It covers work being done both at the Centers themselves and by the contractors and is organized into two categories: (a) prime contractor work which is funded by the work package and which is performed in the development of the baseline Space Station; and (b) work, funded either by the work package or by the Level I Advanced Development Program, which is not part of the primary contract and is not currently intended for the development of the baseline Space Station.

Under (a), two expert systems (one each in Work Packages 2 and 3) are being developed and several activities which support advanced automation are also being conducted.

McDonnell Douglas Space Systems Company (MDSSC), the prime contractor for Work Package 2 at the Johnson Space Center, is developing an expert system for global fault detection, isolation and recovery (FDIR) in the Space Station's OMS which will include a large (e.g., on the order of 3000 rules) knowledge base. This project is at an

early stage, and its capability will be identified at the preliminary design review in early 1990. The FDIR function is quite appropriate for advanced automation; nevertheless, this application is very ambitious and progress will be reviewed with great interest.

General Electric (GE), the prime contractor for Work Package 3 at the Goddard Space Flight Center, is developing an expert system for platform anomaly diagnosis (ESPAD). It will monitor platform telemetry data and fault indications. It will be onboard the platform and will interface with the platform management system (PMS) to detect faults, infer new resource profiles, and schedule payload activities to operate within the resource profile.

GE is also performing an analysis of how the Flight Telerobotic Servicer can interact with attached payload accommodation equipment (APAE). This will confirm FTS's resource requirements, define potential FTS tools, and layout FTS worksites for assembly and servicing of the Station interface adaptor (SIA).

The Rocketdyne Division of Rockwell, International, prime contractor for Work Package 4 at the Lewis Research Center, is working to insure that the electrical power system is designed to be compatible with assembly and servicing by the FTS and the Canadian Special Purpose Dexterous Manipulator (SPDM). They are using computer simulations and are coordinating with GSFC and the Canadian Space Agency, and are insuring compliance with the Robotic Systems Integration Standards document that is now under development by Level II.

Rocketdyne is incorporating a considerable amount of classical or traditional automation into the design of the Space Station Freedom electrical power system. As a result of this approach, much of the power system health and status monitoring sensing components will be directly useable for an advanced automation knowledge-based system for fault detection, classification, isolation and system recovery and reconfiguration, when such a system is developed and ready for implementation.

While these tasks may not seem to constitute a large A & R effort for baseline Space Station Freedom, it must be noted that this is not the result of a lack of strong A & R proposals from the prime contractors and their subcontractors. A number of such proposals were presented to the ATAC. However funding in the baseline contracts is insufficient to cover their inclusion. **ATAC's assessment is**

that the advanced automation efforts in the baseline program are worthwhile but more activities are needed. Because of the potential benefits to operational and life-cycle costs, ATAC urges Level II to direct the work packages and their prime contractors to allocate more up-front resources to baseline Station A & R, as well as to hooks and scars for future A & R applications, even in the face of shrinking funds.

The second category of A & R work to be described in this report is referred to as nonbaseline work. It consists of activities which are not part of the baseline contract with the prime contractor and focuses on the development of technology that may be added to the baseline at a later time as results warrant or which may be added to SSFP in its early evolution. The inclusion of applications such as the above into the baseline Station is a decision between NASA and the contractors based on many factors such as funding, risk, and schedule.

This supporting development activity at the Marshall Space Flight Center includes an A & R graphics test bed, flight robotics laboratory support, telerobotics fluid interface development, and low-G robotics performance testing. Nonbaseline A & R projects at the Johnson Space Center include network monitoring system and intelligent presentation of status information for the data management system (DMS); operations management applications prototype for station-wide fault diagnosis and management; a DMS execution ground controller monitoring interface which will monitor OMA commands to on-board systems; and C & T fault detection, isolation and recovery.

In addition, JSC and MDSSC are also participating in a joint advanced automation methodology project (AAMP) to define and document an engineering methodology for the management, development and verification of SSFP automation applications. It includes the development and documentation of two "bench" applications using NASA's software management and assurance program. The two bench applications consist of an expert system for network monitoring on the DMS and an expert system for recovery of functionality after faults have been detected and diagnosed in the Communications and Tracking System. JSC is responsible for verification of both applications.

The objectives of the Level I Evolutionary Advanced Development program are to enhance baseline SSFP capabilities and to enable SSFP evolution. These tasks are divided into four

categories: Flight Systems Automation, Ground Operations support, Advanced Automation Software, and Telerobotic System Technology.

In Flight Systems Automation there are four tasks: Environmental Control and Life support System (ECLSS) automation task is being done by Boeing and University of Alabama at Huntsville. Candidate approaches to this task are being evaluated and a prototype will be developed. Principal Investigator-in-a-box, at ARC, is a task which is co-funded with Code R's A & R program. It is aimed at developing an expert system which can help an astronaut be more of a co-principal investigator during an on-board experiment. Power Management and Distribution (PMAD) Automation, at MSFC, is also being co-funded with Code R. It concerns expert systems use in PMAD and the development of an enhanced user interface. PMAD automation, at LeRC, is co-funded with Code R. This task seeks to develop expert system capability for failure diagnosis and isolation and load rescheduling. Preparations for a joint MSFC-LeRC demonstration are under way.

In the area of Ground Operations support, there are two tasks. The first, a task for Mission Control Center Real-Time Data Acquisition/ Analysis, at JSC, co-funded with Code R, demonstrated the capability of expert systems technology for aiding mission controllers on Shuttle at four controller workstations. The technology is being transitioned to the Space Station Control Center Test Bed. The second task, Platform Management System (PMS) Automation, at GSFC, is developing the technology for the use of expert systems in the scheduling and controlling of the PMS from the ground.

In the area of Information Systems, a task on OMS Advanced Automation being conducted at JSC has two parts. One is for FDIR prototyping, and the second is for development of an expert system for monitoring resources and making planning judgments. Data Management System (DMS) Advanced Automation, at JSC, is investigating the use of Ada, multiprocessing, and artificial intelligence techniques and hardware on the DMS. The Advanced Automation Test Bed Study at JSC was established following last year's report reviewing SSFP test beds and capabilities for Advanced Automation (ref. 10) and is addressing ways to augment the test beds to support advanced automation. Advanced Automation Tools, at ARC, is a task which is evaluating alternative hardware and architectures, and networking approaches. Technical and Management Information Systems (TMIS) Design Knowledge Capture (DKC), at ARC, expands on the ongoing Code R work on Design

Knowledge Capture, and is aimed at demonstrating DKC capability with regard to the TMIS. JSC and MDSSC are doing operational design knowledge capture as part of their prime contract.

The Telerobotics System Technology effort has four tasks. Telerobotic Evolution Studies, at JPL, involves building human-machine automation trade-off models which will be transferred to Levels II and III. IVA Robot, at MSFC, is a robot tasking and system design tradeoff study which is nearing completion, while development of a lab mockup robot application is proceeding. Tasks to develop architectures for telerobotic systems, at JPL and KSC, have been started and used in the development of a PAM-D Booster Inspection application to use Code R developed technology, from the telerobotics research program, in robotic ground processing. Finally, Automated Construction Techniques, at LaRC, has developed an operational automated truss assembly system. A generalized approach to truss construction and SSF Solar Dynamic assembly will be pursued. More detailed progress for these tasks can be found in appendix A.

ATAC applauds the progress of the Level I Advanced Development tasks and the Centers performing them and the other non-baseline work. The tasks are considered worthwhile in terms of advancing A & R technologies and are of value to the SSFP to enable growth and evolution. Continued leverage of the Code R tasks and coordination with Code R by SSFP is encouraged.

Flight Telerobotic Servicer Progress

During this reporting period, the Flight Telerobotic Servicer Phase C/D (final design and development) contractor was selected to be Martin Marietta Aerospace in Denver. Because of restricted information flow during the contractor selection process, ATAC had not had an opportunity to adequately review the FTS progress. Therefore, after selection, ATAC devoted an entire day of its 2-day meeting for that purpose. **ATAC found that Martin Marietta has made excellent progress on the FTS and the first FTS demonstration test flight (DTF-1) through the good work done on the Phase B contract.** Martin Marietta has selected subcontractors to design and fabricate components of DTF-1, the first FTS flight test. Martin Marietta's FTS concept is illustrated in figure 2. More details on progress of the FTS are contained in appendix B of this report.

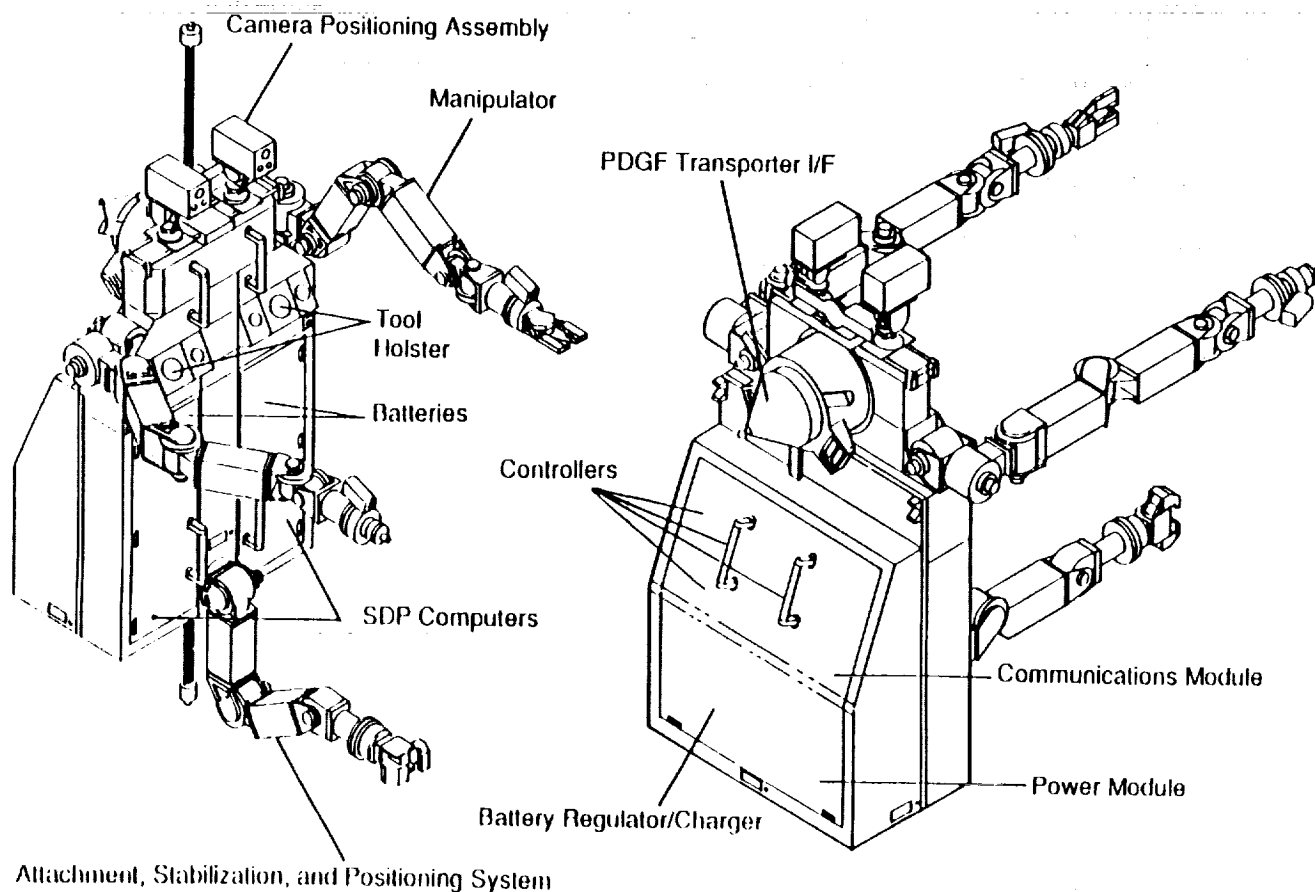


Figure 2. The Flight Telerobotic Servicer telerobot front and back views.

ATAC is very pleased with the progress and status of the FTS. **GSFC and its supporting team is to be commended for defining a servicing concept and establishing and holding to a procurement schedule.** The FTS, as defined by the Phase B effort, can be a relevant system for use on the Space Station. ATAC is particularly pleased with the architecture of the FTS (based in part on technology and concepts developed earlier by OAST) which will allow technical evolution and growth without redesign. Margin is allowed in the computing systems for changes and growth. ATAC feels this is a valuable and needed approach for the FTS. The FTS project has also started a process to define the technology needed for evolution of the FTS. Although FTS has shown a good start in this process, ATAC believes that the preliminary evolution plans are not yet as technically aggressive as desired by the Congress when FTS was chosen as the telerobotic focus for Space Station.

GSFC has also made significant progress with their Mission Utilization Team (MUT) in defining feasible, relevant tasks for the FTS in the Space Station assembly sequence. Obtaining JSC participation, although informal, in the MUT, was productive. Nevertheless, it is still critical that roles and explicit tasks be assigned to the FTS during the SSF assembly replanning process. Studies during this reporting period showed that the FTS could be used during the assembly phase to reduce the number of EVA hours. However, there is still little formal integration with the EVA planning activities. **With the definition of the FTS system and capability now available from the Phase B study, Space Station assembly sequence planners must use the FTS to build feasibility and margin into the Space Station assembly sequence, as recommended earlier in this report.**

ATAC RECOMMENDATIONS

I. Complete the A & R Program Plans at all levels by the end of FY 89. The plans should explain the A & R goals and organization, and should indicate resources and priorities required to complete implementation of planned A & R activities. Delays experienced in completing the plans reflect a perception of low priority for A & R.

II. Establish a hierarchy of full-time dedicated A & R focal points in Levels I, II, III, and the work package contractors. Develop specific responsibility statements for each focal point, including: hierarchal interrelationships, program overview/visibility responsibilities, program management access methodologies, and other factors needed to assure that the focal points have program visibility and management access to assure that A & R is properly considered in the SSFP. Delays and regressions experienced in developing these A & R focal points and hierarchy reflects a perception of a low priority for A & R development by management.

III. Develop objective criteria for evaluating all SSFP technologies, including A & R, to assure that A & R technologies are evaluated on an equal basis. In addition to evaluating technologies on the basis of safety, reliability, schedule, and performance, specific attention should be given to evaluating the payoff of technologies in reducing overall life-cycle costs, and incorporating those advanced A & R

activities which provide significant life-cycle cost benefits. Previous inadequate life-cycle cost analyses for A & R technology implementation proposals have had a detrimental effect on incorporating A & R capabilities into SSFP.

IV. The original work package A & R proposals and high-leverage prototyping proposals should be evaluated against the above stated criteria and the results reported at the next ATAC meeting. The proposed Level II High-Leverage Prototyping Program should be funded and coordinated with the Advanced Development Program to emphasize high-leverage prototype developments during the next year. Proposals which meet the criteria should be funded at a sufficient level to encourage a number of A & R implementations for the evolutionary Station.

V. A unified and formal organizational structure needs to be developed to define all FTS tasks, especially those involving assembly sequences. FTS must be considered as a resource during development of EVA activities, especially as a contingency for maintenance activities during assembly sequences. Previous working groups considering FTS and EVA activities have had informal coordination, however lack of formal recognition and interaction has delayed identification and acceptance of FTS tasks and capabilities.

APPENDIX A

Office of Space Station (OSS) Automation & Robotics (A & R) Progress

The Space Station Freedom Program (SSFP) policy for A & R reflects a commitment to apply A & R technologies in the design, development, and operation of the baseline Space Station. A & R applications will be utilized when found to be appropriate within the context of the overall system design, to have a favorable cost-to-benefit ratio, and where the enabling technology is sufficiently mature. The OSS recognizes that A & R technologies are experiencing rapid change, exhibiting varying levels of technology readiness, and have unique requirements for successful integration with conventional design approaches and system engineering methodologies. Consequently, an important component of the SSFP A & R policy is the provision of design accommodations and mature technology which will permit the program to fully capitalize on the anticipated A & R advances which will occur during the development and evolution of Space Station Freedom. Lastly, the OSS intends to take full advantage of the significant momentum in A & R research and technology development within the government, industrial, and academic sectors during all phases of the program.

Progress has been made by the SSFP in each of the above areas and will be described in the following sections.

A & R Planning and Coordination Activities

The final draft of the Level I A & R Plan is scheduled for completion by the end of September. ATAC Progress Report 7, appendix B, "Overall Plan for Applying A & R to the Space Station and for Advancing A & R Technology", contained major excerpts of the initial draft plan. Sections pertaining to infrastructure and baseline A & R content have been modified and will be reviewed within the program prior to finalization and distribution. The Level II A & R Implementation Plan has been revised to reflect recommendations from the Level II A & R planning retreat held in December 1988, and to reflect Program Director guidelines given in March and July 1989. The publication goal for the plan is September 15, 1989.

An Evolution Plan for the Flight Telerobotic Servicer (FTS) has been developed by the FTS Project Office at Goddard Space Flight Center (GSFC), Level II, and Code ST. The Plan is in

final coordination and outlines growth and evolution options for the FTS and the attendant technology development and implementation requirements. The Plan will help focus the investment of the Space Station Advanced Development Program in telerobotics and will also be provided to the Office of Aeronautics and Space Technology for use in their program planning activities.

An update to the Memorandum of Agreement (MOA) between OSS and OAST concerning telerobotic technology was drafted by Code ST and distributed within the SSFP and OAST. Coordination within the SSFP (Levels I, II, III, FTS Project Office) has been completed; final coordination with OAST is pending. The MOA outlines roles and responsibilities in: the determination of technology requirements for the FTS; technology development and transition activities which enable FTS growth and evolution; and the investment in long-term research to ensure that the identified needs of the FTS program are met. A similar update to the MOA between OSS and OAST concerning Advanced Automation is being drafted to continue the close coordination of research, technology development, and implementation between OSS & OAST.

A & R Progress Within the Baseline Program

A & R Activities at Level II

A & R Management Structure—In response to an ATAC recommendation SSF Level II has made changes to clearly define the roles of individuals responsible for A & R. The new structure maintains the Associate Director for the SSF Level II as the focal point. A & R responsibility for advocacy design and engineering has been delegated to the Group Directors for Operations and Utilization (Code SSU) and System Engineering and Integration (Code SSS). A specific focal point for each of the groups has been appointed. This reduces the number of Level II SE & I staff whose primary responsibility was A & R from 2 to 1. However, each distributed system manager is now responsible for A & R advocacy in their individual area. This will result in an overall increase in the attention given to A & R. The program director has initiated semi-annual progress reports in the area of A & R by the responsible Group Directors.

A & R High Leverage Prototyping—As indicated in the last report to ATAC, Level II decided that a mechanism was needed to develop promising

technologies in the areas of A & R and that the exigencies of developing the baseline SSF precluded the work packages and their contractors from assuming the additional technical, cost and schedule risk that was perceived to be associated with these technologies. High leverage prototyping was conceived as the means for minimizing the concerns with introducing the new advanced automation technologies. It was also intended to bridge the gap between the Level I Advanced Development Program tasks and the baseline SSF development activities.

Work packages were asked to submit short (1 or 2 page) proposals that were responsive to the objectives of the prototyping effort. In addition, several unsolicited proposals were received from companies familiar with the SSF program. Evaluations of each proposal and relative ranking were made by each A & R specialist within the Level II organization. After review by the SE & I division managers there was an overall priority established for all of the recommended prototyping activities. After a final review within SE & I, a presentation of the recommendations to the Program Director was made. At that meeting the A & R specialists were directed to have the proposals redone and highlight the products that would be delivered, address the benefits that would be reaped by including the prototype capability and identify those that could be carried out by the work package prime contractors as additional tasks with additional funding. In the case of advanced automation prototyping, a request was made to supply new or revised proposals from each of the work packages at the Advanced Automation Meeting reviewing PDRD changes. Advanced Automation proposals were received from one work package. A formal request for additional Advanced Automation prototyping proposals will be sent out to solicit proposals from the other work packages. Revised proposals for Robotics High Leverage Prototyping were requested at the last Robotics Working Group meeting.

Proposals were requested in the following areas: Integration of Assembly Work Platform, Astronaut Positioning System, and Flight Telerobotic Servicer for Telerobotic and/or Robotic performance of early assembly tasks (JSC lead with GSFC support). The following proposals were recommended for approval: Ground Control of MSS and FTS (JSC lead with GSFC and CSA support); On-Orbit Nondestructive Inspection/Nondestructive Evaluation (GSFC lead with JSC and JPL support); IVA Robot for Management of Equipment in Logistics

Module (MSFC lead) and Rack-Level Robot for Materials Processing (MSFC lead).

A & R General Requirements in the PDRD—A meeting was held during June at Ames Research Center to review proposed changes to the PDRD sections that are related to A & R. The review was completed during the meeting and the revision of the PDRD A & R paragraphs will be presented to the SSF pre-board after a final review of the proposed changes by the work packages. These modifications define in more specific and verifiable terms the requirements for hooks and scars required to support growth and evolution of A & R. A draft Change Request will be presented to the Systems Engineering Review (SER) forum at Level II during September, 1989, and will be entered into the Configuration Management system for formal review by the program.

Robotics System Engineering and Integration Activities

FTS Assembly Task Selection—An in-depth study is underway to identify assembly tasks which can be effectively accomplished by the FTS. The Assembly Sequence is an important part of this analysis since task sequence plays a part in determining whether task accomplishment by EVA or Telerobot makes more sense. The objective of the analysis is to save EVA time during early assembly flights which are oversubscribed relative to EVA time. The following specific activities are underway:

PDR Assembly Sequence Re-plan—This is an effort managed by Level II to define an assembly sequence which will support the PDR baseline Assembly Complete configuration. The replanning effort has included active analysis of early assembly tasks which are potential candidates for FTS performance. This analysis has included active participation by the Goddard Space Flight Center FTS Mission Utilization Team (MUT) described below. The objective of this activity is to baseline a new assembly sequence for PDR reference by the middle of August, 1989.

MUT Activity—The FTS MUT has analyzed numerous tasks for performance during early assembly flights. The following tasks appear to be suitable for FTS performance, resulting in savings of required EVA time:

- (a) Worksite preparation and cleanup
- (b) Pallet installation
- (c) Radiator panel installation

Assembly Operations Assessment (AOA)—The results of the PDR Assembly Sequence Replanning Activity will be reviewed by the AOA activity which is a joint review by Level II and JSC Operations personnel.

Telerobotic Task Allocation—In addition to selection of early assembly tasks for FTS, a task allocation process is evolving which will select primary, back-up and optional support elements for performance of all SSF assembly, maintenance, and servicing tasks. This process is an integration of ongoing activities at Level II, JSC and GSFC as described below:

Robotic Task Analysis Process (RTAP)—A process document is being prepared by Level II through a contract with Ocean Systems Engineering, which will define a formalized methodology for analyzing assembly, maintenance, and servicing task requirements and matching these requirements with available telerobotic support elements. This process will identify necessary modifications to both task and support element designs required to achieve an effective match of support elements and tasks, and will ensure that there is an intelligent trade-off made between the task design and the telerobot design. The analysis required by this process document will be prepared jointly by the task designers and the telerobotic support element designers and will be reviewed at PDR to ensure that assembly, maintenance, and servicing tasks can be performed using available telerobotic support elements.

Assembly, Maintenance, and Servicing Implementation Definition Document (AMIDD)—JSC is charged with the responsibility for development of the AMIDD. This document will identify all anticipated assembly and maintenance tasks on SSF and allocate support elements for their performance. EVA and telerobotic resources will be allocated as Primary (P), Optional (O), or Back-up (B). The RTAP and MUT activities are being integrated into the decision process for development of the AMIDD allocations.

Servicing System Implementation Definition Document (SSIDD)—GSFC is charged with the responsibility for developing SSIDD. A series of meetings have been held between JSC and GSFC to harmonize the format of the two documents and ensure that the same methodology is used for task analysis and support element allocation.

Hand Controller Commonality—The Workstation Integration Group at JSC has been charged

with the responsibility to analyze workstation requirements and recommend actions necessary to arrive at the required level of commonality from a man-systems standpoint. One of the issues being investigated is hand controller commonality for telerobotic devices. The Robotics Working Group is working with the Workstation Integration Group to identify the functional requirements for hand controllers on SSF and arrive at a set of common requirements. This may or may not drive towards common hand controllers, but as a minimum will ensure functional commonality for the benefit of operator training and efficiency/safety of telerobotic operations. These efforts will likely include some evaluation of hand controller options at JSC and will produce a recommendation to the program no later than June of 1990.

Collision Detection and Avoidance—This issue has received much attention since the Mobile Servicing System (MSS) Preliminary Design Review (PDR) in March of 1989. The approach selected by Canada anticipates significant computational resources being supplied to the MSS through the Data Management System (DMS). An action was assigned to the Robotics Working Group by the MSS PDR Review Board which requires an analysis of PDRD requirements for Collision Detection and Avoidance, investigation of various technical approaches, and estimates of computational resources required for the various approaches. Change requests to the PDRD requirements may result from this analysis. This effort is scheduled to complete in September 1989.

Robotic Systems Integration Standard (RSIS)—The first draft of RSIS has been reviewed by the program work packages and their contractors. Comments have been received and are being integrated. The final draft will be circulated in October for formal RIDs and will be baselined as an applicable document in the PDRD.

LEVEL III A & R ACTIVITY

Advanced Automation in the Baseline Program—Each of the work packages were asked to report on the contractual requirements and actual prime contractor commitments that had been made. The two efforts that were reported to ATAC were:

As part of OMA, a 3000 rule Knowledge-Based System for Fault Detection, Isolation and Repair (FDIR) is planned by WP-2.

A ground-based fault diagnostic system for the Polar Orbiting Platform, that could be migrated to the POP as confidence in its performance is gained, is planned by WP-3.

It was noted that many potentially useful applications were being developed as part of the Level I sponsored Advanced Development Program tasks at each of the Work Package Centers. The contract for FTS was awarded to Martin Marietta in Denver. Refer to the FTS appendix for information on the FTS program.

A & R Progress Within the Transition Definition Program

The Transition Definition Program is divided into two major components, Evolution Studies and Advanced Development. A detailed overview of the Transition Definition Program was provided in ATAC Progress Report 7, appendix B, "Overall Plan for Applying A & R to the Space Station and for Advancing A & R Technology". Additional information can be found in ATAC Progress Report 8, appendix A, "OSS A & R Progress". The Transition Definition Program is managed by the Strategic Plans and Programs Division, Level I, Office of Space Station, and involves all of the NASA centers and each of the SSFP Work Packages.

The top level objectives of the Advanced Development Program are to enhance baseline Station capabilities and enable Station evolution in support of advanced missions (e.g., transportation node for Lunar/Mars missions). The specific objectives are to improve the productivity and reliability of flight and ground systems, reduce operations and sustaining engineering costs, and prevent technological obsolescence. The products of the Advanced Development Program which underpin these objectives include "engineering" fidelity demonstrations and evaluation on Space Station development test beds, design accommodations which permit the insertion of new applications and/or new technology, and, in some cases, mature technology and the tools required to develop and support advanced applications, especially in the A & R area.

Currently, the majority of the Advanced Development Program's FY89 budget of \$8M is dedicated to A & R applications and technology development. Thirty tasks are divided between Flight System Automation (\$2M), Ground Operations & Information Systems (\$2.9M), Advanced Automation Software & Hardware (\$2.2M), and Robotic Systems Technology (\$.95M). Fourteen of the tasks

are leveraged by joint funding from the Office of Aeronautics and Space Technology (OAST), the Office of Space Flight (OSF), the United States Air Force (USAF), and the Defense Advanced Research Projects Agency (DARPA). The joint funding results in an addition of \$12.5M to the tasks. This has enabled the Advanced Development Program to have a considerably greater impact than its funding level would indicate.

In Flight Systems Automation, advanced automation applications are being developed for Power Management and Distribution (PMAD), the Environmental Control and Life Support System (ECLSS), and laboratory module scientific experiments. The applications focus heavily on Fault Detection, Isolation and Reconfiguration (FDIR) and provide a range of support in system safing and reconfiguration. All are a mix of conventional and Knowledge-Based System (KBS) techniques and each provides a powerful user interface to support interactions in an advisory mode.

Major accomplishments during this reporting period include:

Enhancements were made to the PMAD FDIR KBS application software and user interface on Marshall Space Flight Center (MSFC) PMAD test bed; Application re-hosting was initiated to a computer architecture compatible with the Space Station Data Management System (DMS) hardware; Initial analysis of KBS interface and communications requirements for a distributed, cooperating KBS demonstration has been completed;

Failure diagnosis & isolation and associated fault explanation have been implemented in the KBS for PMAD switchgear on the Lewis Research Center (LeRC) PMAD test bed and an electrical load scheduler is being integrated with the diagnosis & isolation KBS to implement intelligent rescheduling; Preparations for a joint demonstration of distributed, cooperating KBS applications between the LeRC and MSFC PMAD test beds are underway;

A prototype KBS experiment protocol manager has been developed at Ames Research Center (ARC) and the Massachusetts Institute of Technology (MIT) which restructures the experiment upon request when faulty instruments, time shortages, or interesting data are encountered for a Spacelab-based vestibular physiology experiment; The experience with pre-flight, flight, and post-mission data on the SLS-1 and SLS-2

Spacelab missions will be used to influence design requirements for Space Station Freedom laboratory experiment interfaces to ensure that analogous capabilities are provided. Crew members and the experiment's Principal Investigator are actively involved in the development.

In Ground Operations and Information Systems, advanced automation applications and the computer and network architectures required to enable them for the baseline Station are being addressed. Applications are under development for the Mission Control Center (MCC) and Space Station Control Center (SSCC), the Earth Orbiting Satellite (EOS) Platform Management System (PMS), the Space Station Operations Management System (OMS), the on-board Data Management System (DMS), the Software Support Environment (SSE), and the Technical and Management Information Systems (TMIS). As with other applications, all are a mix of conventional and KBS techniques and each provides a comprehensive user interface to support interactions when used in an advisory mode.

Major accomplishments during this reporting period include:

Development and use of a real-time KBS application for Shuttle mechanical systems which logged, plotted, calibrated, and corrected tire pressure measurements during all mission phases of STS-30; Demonstration of a distributed KBS monitoring and analysis capability via a remote Integrated Communications Officer (INCO) console in the Mission Evaluation Room during STS-30 (INCO was described at length in ATAC Progress Reports 7 and 8); Re-hosting of these new applications as well as the existing MCC real time KBS applications (e.g., Space Shuttle Main Engine monitoring, INCO) to the Transition Flight Control Room (TFCR) to influence the design and architecture of both the MCC Upgrade and the SSCC has been initiated;

Integrated the PMS Scheduling, Architectures, and Networks Test Bed at the Goddard Space Flight Center (GSFC) with the Laboratory for Atmospheric & Space Physics at the University of Colorado (LASP/CU); Development of a KBS scheduler/controller which automatically accesses schedule databases, generates resource requests, and recognizes and reschedules conflicts for LASP/CU instruments has been started; The requirements specification for the PMS Ground Segment Schedule Manager has been completed and reflects KBS implementation requirements; A long-range PMS Evolution

Plan has been developed which addresses the integration and use of advanced automation in EOS operations;

Completed an OMS FDIR baseline document which establishes functional goals for global distributed system FDIR using conventional and KBS techniques; an initial prototype is under development which will monitor DMS health & status and perform safety/time critical fault recovery; A KBS application prototype for the OMS which monitors available on-board resources and makes judgments concerning the validity of the short term plan event execution has been developed with later versions to perform limited replanning and re-scheduling;

Updated the DMS Advanced Development Plan to incorporate the results of an advanced operating system study of Ada language and multiprocessor architecture impacts; Defined interfaces and configuration commonality requirements between the Johnson Space Center (JSC) DMS test bed and the ARC Advanced Architectures Test Bed, joint tests and evaluations are being planned to define requirements and interface specifications (hardware and software) for high-performance fault tolerant multiprocessors; A DMS Network Test Procedure Executive KBS which supervises operating system utilities, workload processes, and network monitoring applications has been developed at ARC and will be transitioned to the JSC DMS test bed pending performance evaluation;

Demonstrated a knowledge acquisition tool and user interface that supports a facet of Design Knowledge Capture (concept described in earlier ATAC reports); Prototype is under evaluation by Level II to support the Preliminary Design Review process and will be re-hosted to permit integration with TMIS hardware and software; Discussions have been initiated with MSFC Work Package personnel (NASA and contractor) to select a baseline engineering design application to evaluate the prototype.

Progress has also continued in tasks which are developing software tools to support the development of advanced automation applications. A prototype programming environment for generating Intelligent Computer-Aided Training systems which use multiple KBSs to customize training scenarios and track student progress is nearing completion and will be evaluated against ground operations training requirements; The development and evaluation of Ada-based KBS programming tools and

run-time environments will yield two prototypes for evaluation in early FY 1990, one is derived from Inference Corporation's Automated Reasoning Tool (ART@) product and the other is based on the NASA/JSC developed C-language production systems (CLIPS) tool. Each will be evaluated using existing KBS application software and design requirements for the Software Support Environment (SSE) will be derived; A second prototype of an Automated Software Development Workstation (ASDW) has been delivered to JSC and is being evaluated by the Mission Operations Directorate for use in MCC software maintenance. ASDW provides a KBS interface which assists the programmer in rapidly developing large programs through the reuse of existing Ada software modules; ASDW is under evaluation for incorporation in the Space Station SSE.

In Robotic Systems Technology, an emphasis has been placed on the development of sensor and control architectures to increase the degree of autonomy in the Flight Telerobotic Servicer (FTS) and to develop the necessary technology components to enable teleoperation with low bandwidth communication and time delay similar to that experienced between the ground and low earth orbit. Extensions to and refinements of the NASA Standard Reference Model (NASREM) control architecture to better integrate technological advances in sensing, perception, and control will be one of the products of the tasks underway. Additionally, the design of "robot friendly" interfaces and assembly/maintenance procedures is being addressed for post-baseline robotic assembly, maintenance, and servicing operations.

Major accomplishments during this reporting period include:

A human-robot task performance model has been developed at the Jet Propulsion Laboratory (JPL) to assist in task assignment tradeoffs and component technology assessments; An automated database management system is being added to the model and it will then be transferred to Level II, the FTS Project Office, and the Level III Work Packages;

A tradeoff study for an Intravehicular Activity (IVA) laboratory module robot is nearing completion at MSFC; Development of a mockup and robot application task using Spacelab racks and materials processing experiments is proceeding;

The Langley Research Center (LaRC) Automated Construction Test Bed task is progress-

ing well. The tailored end effector for handling/installing truss struts has been completed and integrated with the robot. The overall system includes a jiggling fixture for the truss structure, the robot/end effector (attached to a moveable platform), and the truss member storage cannister. At present, the system has been able to consistently assemble the inner ring (24 truss members) of a tetrahedral truss structure. The next phase is to integrate more complex planning, collision avoidance, and manipulation problems associated with assembly of the second truss structure. The assembly of the Solar Dynamic Reflectors is under evaluation as the next task for the test bed system. Considerable EVA savings are expected. Both LeRC and GSFC/FTS Project Office personnel will be involved during the execution of this phase of the task.

Development by JPL and the Kennedy Space Center (KSC) of a prototype robotic inspection system for the Shuttle Vertical Payload Inspection Facility is underway; A Payload Assist Module (PAM-D) booster has been installed in the KSC Robotics Application Development Laboratory (RADL) and specific inspection points have been picked, Computer-Aided Design (CAD) models have been developed and installed, and a real-time communications link to transfer image data and commands has been established between KSC and JPL; Control laws, robot path planning and collision detection algorithms, and operator interface decision aids are being developed to demonstrate teleoperation with time delay equivalent to ground operation of the FTS.

The projected Fiscal Year (FY) 1990 budget for the Advanced Development Program is \$17M. The majority of the on-going FY 1989 tasks will be expanded in scope and funding commensurate with their progress. The level of joint funding by OAST, OSF, USAF, and DARPA is expected to increase during FY90. The following guidelines were sent to the NASA centers to focus their FY 1990 new start proposals:

Advanced Automation Applications (e.g., monitoring & control of distributed systems, mission operations, training, software development);

Advanced Automation Technology (e.g., real-time KBS techniques, KBS development & deployment environments, fault tolerant software architectures, KBS verification & validation techniques);

Advanced Human-System Interface Technology (e.g., proximity operations monitoring & control, virtual workstations, robot operation with time delay);

Processor and Network Architectures (e.g., reduced instruction set computer architectures, multi- and parallel processors, functionally/physically distributed fault tolerant architectures);

Telerobotic Applications & Technology (e.g., FTS evolution, autonomous inspection & repair, EVA Crew & Equipment Retrieval, automated construction techniques, end-effectors & tools);

Photonic Technology Applications (e.g., LEO to ground optical communications, optical data storage & processing, advanced optical network protocols & topologies);

Enabling Technologies for Space Station Evolution (e.g., on-orbit cryogen storage & handling, distributed system growth & technology insertion, structures & materials, autonomous rendezvous & docking, assembly & servicing).

The centers submitted 149 proposals for consideration, 65 of which were in A & R categories with an aggregate FY 1990 cost of \$26.1M. At present, the available budget for Advanced Development Program new starts is projected to be \$5M. Consequently, new start selection will be based upon a review guided by the proposal evaluation objectives outlined below. The forms used for the evaluation contained a mix of quantitative and qualitative questions that were structured to permit the evaluators to score the proposal based on requirements and technical relevance, and suggest technical and programmatic modifications to identify opportunities for coordination and joint funding. Integration

with the research and technology development activities of OAST and OSF was of particular interest and their participation in the evaluation process helped shape the proposals selected for initiation in FY 1990.

Evaluation guidelines:

Review objective, approach, technical content, & funding adequacy

Insure relevance to SSFP requirements/needs (explicit & derived)

Align key milestones/products to be consistent with SSFP decision points

Identify Level I/II/III/Contractor personnel to review &/or participate in the task execution phase & transition products/results to SSFP

Identify documents, reports required by task team as background material

Identify potential joint/coordinated tasks with other Codes/Agencies

To insure that the new tasks were well-coordinated with Level II high-leverage prototyping activities and SSFP baseline requirements and also leveraged the activities of other NASA organizations, the proposals were distributed to individuals in each organization and they were asked to evaluate those they thought relevant to their area of responsibility. The organizations included: Level I (ST, SU), Level II (SSE, SSR, SSU), the Office of Space Flight (Code MD), the Office of Space Science and Applications (Code EB, Code EC), the Office of Aeronautics and Space Technology (Code RC, RS), and the Office of Exploration (Code Z).

APPENDIX B

FLIGHT TELEROBOTIC SERVICER PROGRESS

The following information represents the current status of the FTS Project:

FTS Prime Contract

Martin Marietta Astronautics Group in Denver, Colorado was selected for negotiations on April 20, 1989. Negotiations were held during June, 1989, and the contract was awarded on July 31, 1989. The Martin Marietta telerobot concept is shown in figure 1. The present Martin Marietta system and subsystem designs are discussed in this appendix as well as operational scenarios for the assembly, maintenance, servicing and inspection tasks which are being considered for the FTS. The design is expected to undergo some changes as the result of design reviews and space station interface changes.

The next major FTS milestone with space station is the development of the interface control document between the Space Station Freedom and the FTS. This document will establish the worksite accommodations for the FTS including power, data and video resources. It will also establish the location and attachment of the FTS Storage Accommodation Equipment (SAE) which will house the FTS telerobot, tools and spare parts.

Development Test Flight (DTF-1)

The present concept for the Development Test Flight is shown in figure 2. The manipulators and the upper torso of the telerobot body are mounted to a Multipurpose Experiment Support Structure (MPESS) bridge. There will be a single task board attached to the MPESS which will contain the task elements which will be manipulated during the flight. An astronaut will teleoperate the DTF-1 from the workstation located on the aft flight deck of the orbiter with two mini-master hand controllers and television screens that display images from the four cameras that are located on the telerobot. There is also a fifth global-view camera that will be set apart from the telerobot for viewing the entire work area.

A three day Preliminary Design Review for the DTF-1 mission was held at GSFC July 19-21, 1989 under an extension of the preliminary design contract. The review committee was selected by the GSFC Office of Flight Assurance and was comprised of expert NASA engineers from

GSFC and JSC including Greg Harbaugh from the Astronaut Office. The review was attended by representatives from JSC, KSC, LaRC, JPL and space station levels I and II. The action items from the review are being worked by GSFC, with the help of Martin Marietta.

Two major milestones are scheduled for September. They are the review of the DTF-1 Payload Integration Plan (PIP) and the Phase 0/1 Safety Review. The DTF-1 is presently scheduled for launch in September, 1991.

FTS Technical Description

The FTS is a system consisting of a telerobot, a workstation for the shuttle orbiter, a workstation for the space station, spare parts and the storage accommodation equipment for storing the telerobot, its tools and spares on the space station. Included as part of the telerobot are two manipulator "arms", an attachment, stabilizing and positioning subsystem (ASPS) or "leg", cameras and lights, and all end-of-arm tooling. These items are attached to the telerobot central torso which houses supporting subsystems.

The workstations are the principal point of human interaction for the control of the telerobot. Each workstation will be equipped with two 6 degree-of-freedom (DOF) mini-master force reflecting hand controllers. Video displays in the workstation will be capable of displaying up to three video images simultaneously, or two video images with health and status information displayed on the third screen. The telerobot cameras will be voice controlled, allowing the operator to maintain both hands engaged in manipulator teleoperation.

The telerobot will have a set of tools and end effectors that can be autonomously selected through the use of the end effector change-out mechanism (EECM) located on the end of each manipulator. Tool holsters located on the front of the telerobot body store extra end-of-arm tooling when not in use.

There are three ways that the FTS can be operated: fixed-base dependent operation, fixed-base independent operation and transporter attached operation.

In the fixed-base dependent operation the telerobot is attached and stabilized to a worksite and derives its power, data and video from an integral connection at the worksite attachment or an umbilical to a nearby utility port.

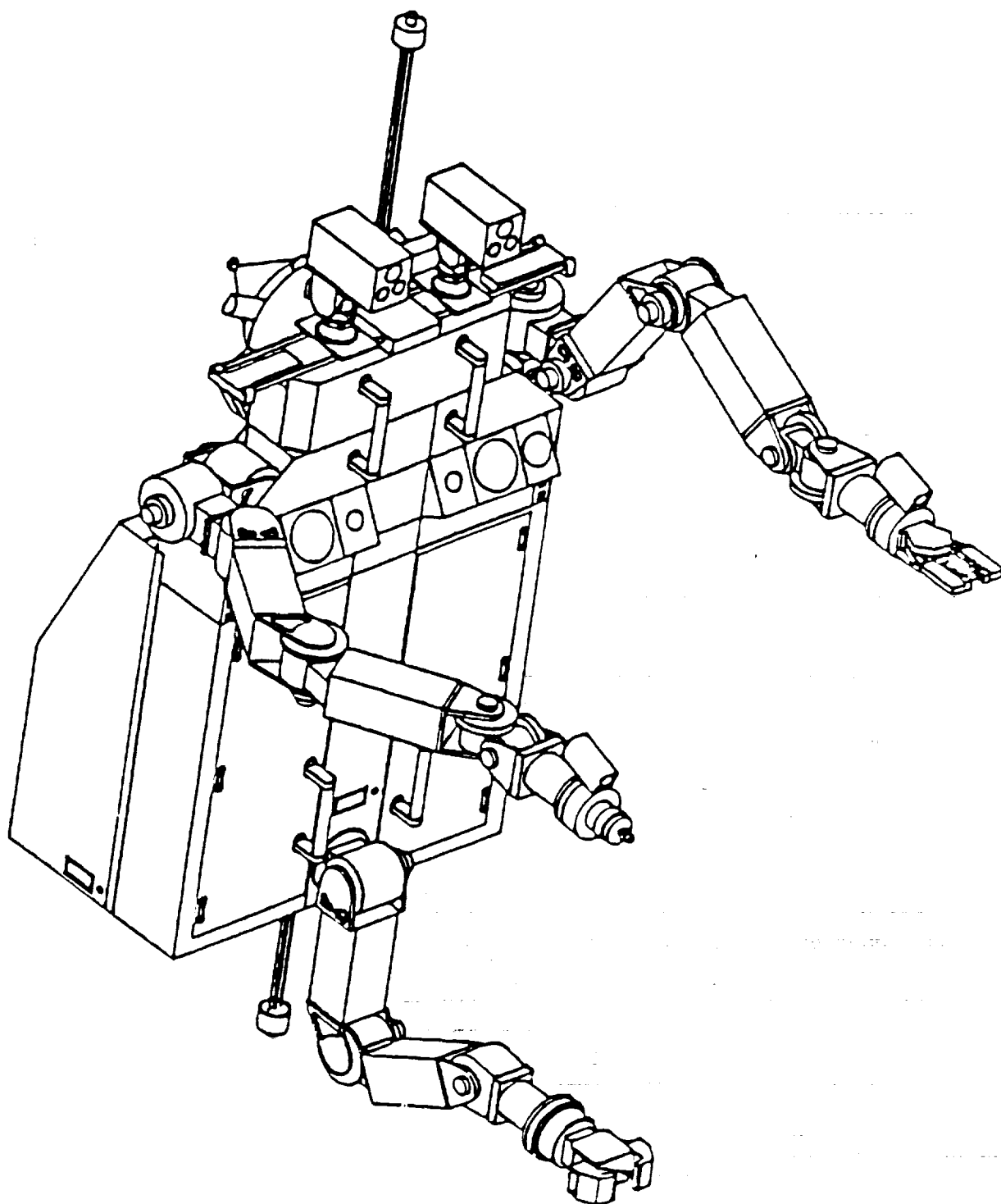


Figure B1. The Flight Telerobotic Servicer (FTS).

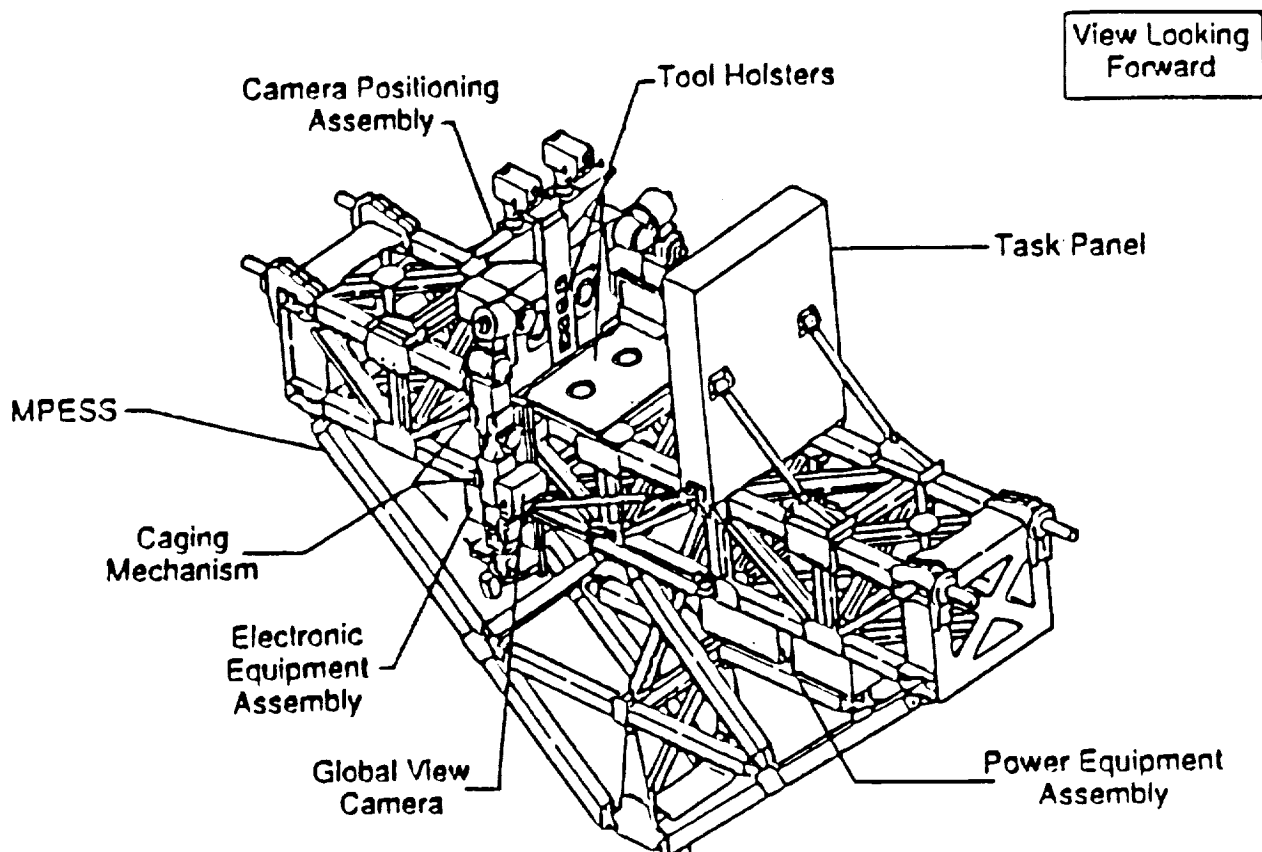


Figure B2. Configuration of payload bay element for the Development Test Flight (DTF-1).

In the fixed-base independent operation the telerobot is attached and stabilized to a worksite but derives its power from its own internal batteries. Communication between the telerobot and the workstation is by a wireless link through the space station communications system.

In the transporter attached operation the telerobot is attached to an external transporter device such as the shuttle Remote Manipulator System (RMS), the space station Mobile Servicing System (MSS) with the space station RMS (SSRMS) or the Orbital Maneuvering Vehicle (OMV). The telerobot derives its power, data and video by way of a hardwire connection from the host transporter.

The total weight of the telerobot and the shuttle workstation will be less than 1500 lbs. In the stowed configuration the telerobot will fit in a volume that is 7 ft \times 3.5 ft \times 3 ft, allowing it to fit through a space station hatch for Intra Vehicular Activity (IVA) servicing. The power required by the SSFTS will not exceed 2000 watts peak power, 1000 watts average power and 350 watts standby power.

Manipulators and End-of-Arm Tooling

The FTS telerobot contains a pair of 7 degree-of-freedom manipulators which are approximately 5 feet long from the shoulder to the tool plate. The kinematics of the manipulators are symmetric with roll-yaw-pitch at the shoulder, pitch at the elbow and a pitch-yaw-roll at the wrist. The manipulators are capable of producing a tip force of 20 lbs. anywhere within the work envelope.

The manipulator joint actuators each include a brushless dc torque motor, harmonic drive transmission, output torque sensor, output position sensor, fail-safe brake, cable wrap and the housing and bearings required to carry structural loads. The brakes are designed to release when power is applied and engage when power is removed.

The manipulators have a repeatability of less than 0.005 inch in position and ± 0.05 degree in orientation. The incremental motion of the manipulators is less than 0.001 inch and less than 0.01 degree at the center of the tool plate. The SSFTS will have a system accuracy of 1.0 inch in position and ± 3.0 degrees in orientation. These

capabilities allow the FTS to be programmed for structured autonomous operations.

The manipulators are backdriveable to allow stowing by an EVA astronaut or by another manipulator. The manipulators have camera assemblies mounted on the wrist roll assembly to allow the operator a close view of the end effectors and tools and the objects that they are manipulating. A force/torque sensor is mounted on the end of the manipulator to measure the forces and torques produced at the tool plate. The tool plate accommodates pass through of power, data and video to the end effectors and tools. The tool plate also accommodates the manipulator affixed element of the EECM by which tools and end effectors are automatically exchanged by the telerobot.

Attachment, Stabilizing and Positioning Subsystem

A third appendage or leg on the telerobot is called the Attachment, Stabilizing and Positioning Subsystem (ASPS). Its primary purpose is to attach the telerobot to the worksite and to position the body so that the manipulators can properly approach the task. The ASPS must be stiffer than the manipulators and be capable of locking rigidly in place so that the forces and torques generated by the end effectors and tools can be properly reacted to the worksite attach point.

The ASPS is a 5 degree-of-freedom manipulator which is a little over 4 feet long from its base to the tool plate. The kinematics are roll-pitch-pitch-pitch-roll. The actuators are each capable of 24 ft.lbs. of torque. When locked the brakes are capable of 180 ft.lbs. in the two shoulder actuators, 210 ft.lbs. in the elbow, and 240 ft.lbs. in the two wrist actuators. The minimum braked stiffness is 200,000 ft.lbs./radian.

On the end of the ASPS is the Worksite Attachment Mechanism (WAM) by which the telerobot attaches to a fixture located at each worksite [see figure 3]. For fixed-base dependent operations the WAM makes electrical connection to the space station power, data and video systems at the same time that it makes the mechanical connection. Self-aligning scoop-proof connectors in the WAM are mated when the WAM pulls itself into the attachment fixture. This interface has not yet been standardized with the Space Station Freedom Program and it is one of the topics for upcoming interface discussions.

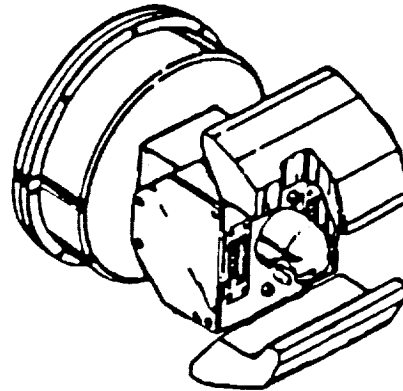


Figure B3. The FTS Worksite Attachment Mechanism.

Data Management and Processing Subsystem

The Data Management and Processing Subsystem (DMPS) hardware and the software that executes in it are critical subsystems of the FTS. The space station FTS (SSFTS) DMPS is a highly distributed processing system comprised of multiple computers and networks which meet the stringent space station safety and reliability requirements. The DMPS implements a fault tolerant, redundant architecture which provides extensive growth capability because of its modularity.

The SSFTS DMPS is physically distributed: throughout the telerobot itself, in the FTS storage accommodation equipment, and packaged with the hand controllers at the workstation. In addition to the computers provided by the FTS, the DMPS interfaces with the computers contained in the space station Multi Purpose Applications Console (MPAC) which hosts the FTS workstation on the space station manned base.

All FTS processors are in the 80386/80387 family of computers, which is the space station standard. The computers are connected through standard space station networks. All FTS processors access 1553b networks. The computers internal to the telerobot use redundant 1553b busses for communication. The FTS computers housed in the storage accommodation equipment are also connected to the space station Fiber Distributed Data Interface (FDDI) network.

The FTS computers include both space station Standard Data Processors (SDP) and special purpose FTS joint controllers. The SDPs are used for high level control and monitoring functions. The joint controllers perform servo level control

of the manipulators, end-effectors, cameras, hand controllers, etc. Redundant processors provide backup capability in the event of failures of primary processors.

The SSFTS DMPS provides approximately 40 Million Instructions Per Second (MIPS) of processing power distributed among 16 joint controllers and 4 SDPs. The telerobot contains 14 joint controllers and 2 SDPs. The storage accommodation equipment houses 2 SDPs. The portable hand controllers contain 2 controllers. Later, additional capacity will be added as the FTS evolves toward autonomy. As an example, additional computers could be added for vision processing.

The flight software that executes in the DMPS must perform complex real-time processing. It is both CPU and I/O intensive. The basic control cycle runs at 50 Hz. so that the teleoperation of the manipulators appears instantaneous to the operator on his video monitors.

Every 20 milliseconds the software must complete all processing and communications associated with the control cycle. This includes sampling the sensors in the hand controllers, interpreting the sensor data as either position or resolved rate commands, integrating the commands into Cartesian coordinates, converting the Cartesian commands through closed loop form inverse kinematics into joint angle commands for the manipulators, and outputting the commands to each actuator in each manipulator and end effector. To close the loop, the entire sequence is reversed by sampling the sensors in the telerobot, translating coordinates, scaling and indexing, and commanding the actuators in the hand controllers to provide force feedback. In addition to the basic control cycle, the FTS flight software must interface with the space station Operational Management System (OMS), monitor and control all FTS subsystems, perform collision avoidance processing, and support all the text, data and graphics interaction with the operator.

The NASA/NBS Standard Reference Model for Telerobot Control System Architecture (NASREM) provides the architecture for the FTS flight software. NASREM defines a set of standard hierarchical and horizontal modules and interfaces that correspond to different levels of autonomy. By adhering to NASREM, the FTS software can be developed incrementally. Initially, FTS will be primarily a teleoperated machine. With time, increased capability will be added allowing for the evolution to more autonomous capabilities. By enforcing the NASREM architecture on the FTS

software, the addition of new modules and the exchange of existing modules with more advanced algorithms is facilitated. NASREM will be used for all FTS flight software, including the two shuttle test flights. By SSFTS, the flight software will implement the first four levels of NASREM. The FTS flight software will be implemented in Ada.

Workstation and Hand Controller Subsystems

The workstation is the man machine interface to the FTS, providing the displays and controls that permit the FTS to be operated by a single individual. The degree of human interaction with the workstation and its location is a function of the evolutionary state of the FTS. Initially, FTS requires teleoperation through master hand controllers that are located on orbit with the slave manipulators. Teleoperation from the ground is impractical due to the time delays associated with radio frequency (RF) communications. In the future, when the FTS evolves into an autonomous robot, hand controllers will no longer be the primary means of control. At that time, the FTS workstation may be on earth.

During the two DTF flights and during the early Space Station Freedom assembly missions, the FTS will be operated by an astronaut from the shuttle Aft Flight Deck (AFD). Later, when the Freedom Station is more complete, the FTS will be operated from workstations located inside the pressurized modules. When the FTS is mounted on an OMV, it will be operated from a workstation that could be located anywhere, perhaps even on the ground.

The FTS STS workstation consists of a display assembly panel, hand controllers, operator restraint system, and electronics. The hand controllers and the display assembly panel are stowed in the mid-deck lockers for STS launch and landing. The electronics are mounted before launch in the L10 payload station. The FTS display assembly panel will be unfolded by the astronaut and mounted to the A6 panel prior to FTS activation. It contains three flat panel color displays that will be used by the operator for display of any three FTS video cameras. Optionally, one of the displays can be used by the operator to view computer generated text and graphics. The FTS shuttle workstation also contains audio caution and warning indicators and lights, voice recognition hardware, keyboard, various hard wired control switches, video recorders, data recorders, and electronics. The STS FTS restraint system, which is required because of the torques caused by the hand controller force reflection, consists of the Mission Specialist's chair

reversed to face aft. The FTS hand controllers are mounted on the chair by the astronaut on orbit.

The SSFTS workstation, depicted in figure 4, will use the standard MPAC, which provides the electronic interfaces between Space Station Freedom application programs and on-board operators. This will be augmented by portable FTS hand controllers so that FTS can be operated from one of several workstations. The restraint system for the space station will be designed on the basis of the evaluations of operator performance during the shuttle test flights.

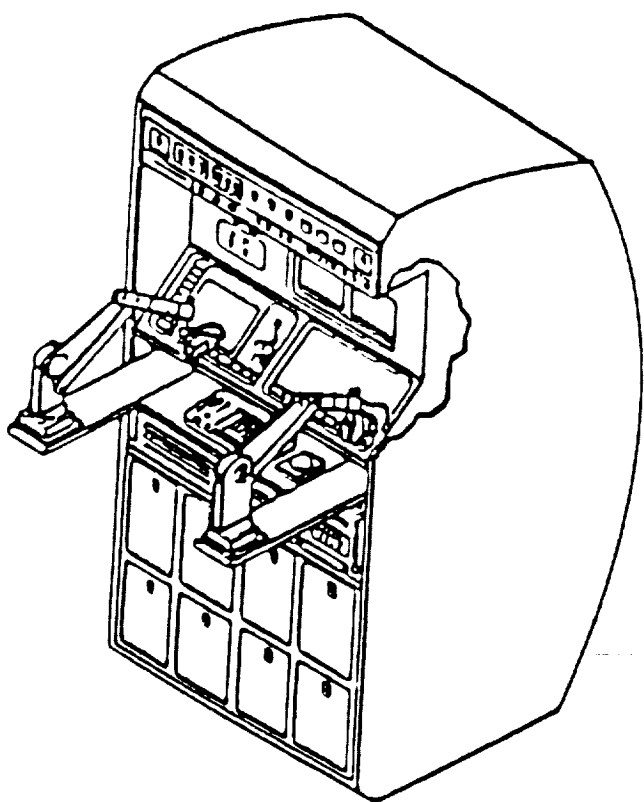


Figure B4. The Space Station Freedom FTS workstation.

The FTS hand controllers are Martin Marietta/Kraft 6-DOF, force-reflecting hand controllers, as illustrated in figure 5. The FTS design is an adaption of a mature design that has been in use in nuclear and undersea applications since 1980 and is the leading force-reflecting hand controller in use today. Among the improvements for FTS are shifting the wrist joints to a coincident point of rotation and adding force feedback to the wrist roll. The hand controller developed and

tested on DTF-1 will be the basic approach for all FTS missions.

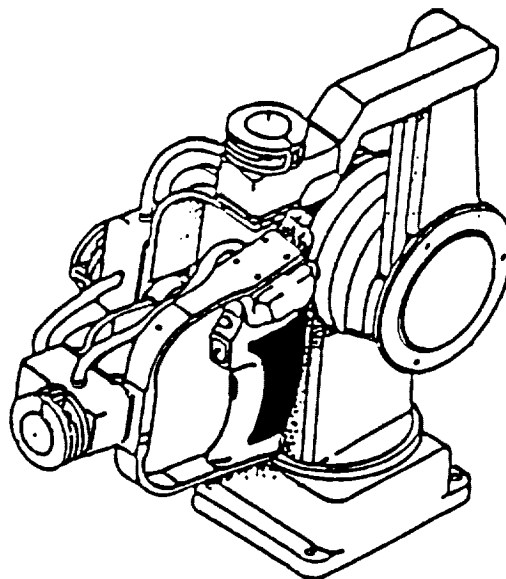


Figure B5. The FTS six degree-of-freedom hand controller.

The FTS hand controllers support an intuitive relationship between the operator's shoulder, elbow and wrist movements and those translated to the manipulator. They can be used for both position and rate control. Because of the force reflection requirements, the FTS hand controllers themselves are robots having actuators and sensors and they are tightly coupled to the FTS controls processing. The FTS operator will use voice commands to control the cameras, so that he/she does not have to release the hand controllers to adjust the cameras. Switches on the hand controllers are used to enable any potentially hazardous activity, such as changing end effectors.

Vision Subsystem

The SSFTS Vision Subsystem consists of color cameras, lighting and video switches. There is one camera on each manipulator wrist with positioning provided by the manipulator. Two head cameras are mounted on Camera Positioning Assemblies (CPA) for global viewing. Also, the ASPS is scarred for the later addition of a camera for use in autonomous docking. Focus, aperture, head camera positioning and light are all controlled by the vision subsystem. Each light will have the capability of providing up to 100 foot-candles of illumination. The 4 video channels are routed through a 6 by 4 video switch to either analog-to-digital (A/D) converters for the RF link or an umbilical for transmission to the SSF C & T video processors.

The C & T video processors select and process the signals to be displayed on the workstation monitors. For the early flights when the SSFTS is operating from STS, the 4 channels will be transmitted via umbilical to a 5 by 3 video switch in the payload bay. Three of the four channels can be selected for display at the STS workstation.

Communications Subsystem

The Communications Subsystem (COMS) provides the two-way RF communication link between the telerobot and the workstation, and the one-way RF EVA safing link between the EVA astronaut and the telerobot. The communication links provide command data from the workstation to the telerobot, and telemetry data and video from the telerobot to the workstation.

The COMS is comprised of a Ku-band Video/Telemetry/Command data transceiver, and the EVA safety shut down functions of a Ku-band EVA safety shut down transmitter and EVA safety receiver.

The COMS is a Ku-band transceiver and is compatible with the SSF Communications and Tracking (C & T) system. The COMS modulates and transmits telerobot video data (up to four video channels) and telerobot health and status data on two Ku-band carriers. These carriers are received and processed by the SSF C & T. Likewise, the COMS receives and demodulates telerobot command and control data that is transmitted from the space station C & T.

The COMS also receives power-up command and control, and transmits status and health when queried, from within the telerobot storage accommodations on space station.

The COMS module houses the baseband modulator microwave transmitter and command demodulator and provides all necessary interfacing to the computers and power system. The COMS amplifies and transmits the digitized video and telemetry data on two carriers at 14.63 GHz and 14.67 GHz respectively. The EVA safety receiver also operates at Ku-band but its operating frequency has not been determined.

The antenna assembly consists of one Ku-band circularly polarized omnidirectional antenna. Two antenna assemblies are mounted on the telerobot, one located on the top and the other on the bottom of the telerobot. The Ku-band antenna is approximately 0.7 inches in diameter

and 0.5 inches high and sits on an extendable boom that can be retracted for telerobot stowage.

The EVA safety shut down transmitter is on the EVA suit. Each EVA safety shut down transmitter will be activated by a simple switch. To satisfy the fail safe requirement, the transmitter will transmit a "heartbeat" version of the safety shut down code when safety shut down is not activated to indicate a healthy transmitter.

Power and Electrical Subsystems

The Power/Electrical subsystem receives power from the SSF or the National Space Transportation System and provides conversion, regulation and distribution of power for telerobot use. An independent power capability is provided by an internal battery for detached telerobot operation, to provide uninterruptible power to safety critical loads and to maintain keep-alive power for critical telerobot memory. Load control and circuit protection for FTS loads and interfaces are also provided by the Power/Electrical Subsystem.

The Power/Electrical Subsystem interfaces with NSTS power at 28 VDC and SSF power at 120 VDC. The 120 VDC power from the SSF is conditioned (with a 120 VDC to 28 VDC converter) to provide a common 28 VDC "Main Bus" voltage for distribution at 22 to 32 VDC within the telerobot. The Battery Module Unit consists of three NASA Standard 20 AH Batteries and a dedicated charger. The batteries are sized to support 2 hours of telerobot detached operations.

Thermal Control Subsystem

The SSFTS is required to operate under all environments for indefinite task durations while working on the NSTS and SSF. The SSFTS thermal design meets this requirement with an approach that is fundamentally passive, relying on selected coatings, special shielding, and carefully chosen equipment placements and mountings. It is augmented with controlled electrical heaters on selected components to compensate for varying power dissipation levels.

The exterior surfaces of the SSFTS are used to balance external heat loads against heat loss to space and thus maintain required temperature levels and to reduce sensitivity to orbital and orientation environmental variations. Internally mounted equipment boxes and interior surfaces are generally coated with a flat absorber (black) type coating for interior group component temperature control.

Workstation equipment are located in the pressurized compartments with the crew. This equipment is maintained within their allowable temperature limits by air cooling in the STS aft flight deck or SSF node.

Control Algorithms

The FTS control algorithms support all the telerobot operations in both teleoperated and autonomous modes. They also support bilateral force reflection, which enables the operator to experience the forces and torques sensed by the force/torque sensor at the tool plate of the manipulators. Bilateral force reflection has a number of advantages for teleoperation. It improves safety by giving the operator immediate confirmation that the manipulator has come in contact with another object. It reduces training time and eliminates errors by giving the operator a more natural feel for the operations and the environment.

Force reflection has a low data latency requirement which must be satisfied by the data system on the space station. For force reflection to be useful it requires a minimum around-the-loop control rate of 50 Hertz. This means that all the control computations and the data transfer from the hand controllers to the manipulators and from the manipulators back to the hand controllers must be accomplished in 20 milliseconds. Half of this 20 milliseconds is allocated to data transmission, which means that the control calculations must be completed in 10 milliseconds under all operating conditions.

Initial tests using coded algorithms in machines with equivalent speed to the flight computers indicates that the 10 milliseconds is achievable with some margin. The biggest uncertainty was whether the space station Data Management System (DMS) would be capable of meeting the FTS data latency requirement, considering the amount of traffic on the DMS bus. Presently the DMS is considering a dedicated bus for the FTS in order to meet the data latency requirement.

The control algorithms provide a number of features that make the FTS a safe and useful tool for the astronauts. The operator will have the capability of selecting and defining coordinate reference frames and he will be able to perform dual-arm coordinated control of a grasped object using a single hand controller. The control algorithms are also capable of shared control in which the operator controls motion in one or more coordinate axes, and the telerobot autonomously controls the motion in

the other axes. The algorithms provide a smooth, safe transfer between autonomous and teleoperation control. They also insure that manipulator singularities can be driven through and that joint stops can be reached and recovered from. There are backup methods of control being investigated so that the operator will be able to reconfigure the FTS for safe transport in the event of a failure of the primary system.

FTS Task Analysis

The GSFC Mission Utilization Team (MUT) has been evaluating potential FTS assembly, maintenance and servicing tasks through the use of the Task Analysis Methodology Document developed by the team. The output for each task is an operational script that isolates individual task activities of the FTS, the RMS, the Astronaut Positioning System (APS) and the Mobile Servicing Centre (MSC). In addition, the stability/resource attachment points for the FTS attachment, stabilizing and positioning subsystem (ASPS) and hand hold locations are defined. Reach capabilities are assessed either through use of Computer Aided Design (CAD) video models or small-scale physical models with the proper kinematics.

This process has identified tasks that contribute to the assembly of Space Station Freedom and reduce the amount of crew extra-vehicular activity (EVA) time. One of the potential tasks presently under investigation is the installation of resource pallets using the FTS. These are the large, table-like structures that attach to the nodes of a truss bay and support elements of the various space station systems, such as the guidance, navigation and control system.

The operational approach is to perform FTS tasks prior to EVA during a three hour period when the astronauts are preparing for the EVA. The task analysis must be sensitive to the operational flow, e.g., a truss must be built prior to the installation of a pallet by the FTS.

Figure 6 shows the FTS attached to the Astronaut Positioning System (APS) during installation of a typical pallet. The RMS has located the pallet so that the four legs are in the vicinity of their respective attachment points at the truss

nodes. The FTS softdocks the pallet to the truss while stabilizing with one manipulator system to a truss node. After performing the leg attachment, the APS moves the FTS to each leg in turn. For those pallets where the fourth attachment is outside the APS/FTS reach, the RMS releases the pallet (which is still held at three attach points), attaches

to the FTS grapple and transports the FTS to the final attachment location. The FTS operates while on the RMS for this operation and for the connection of the pallet utility harness to the space station utility tray. Local stabilization is achieved by attachment of one manipulator to the truss, pallet or utility tray as required.

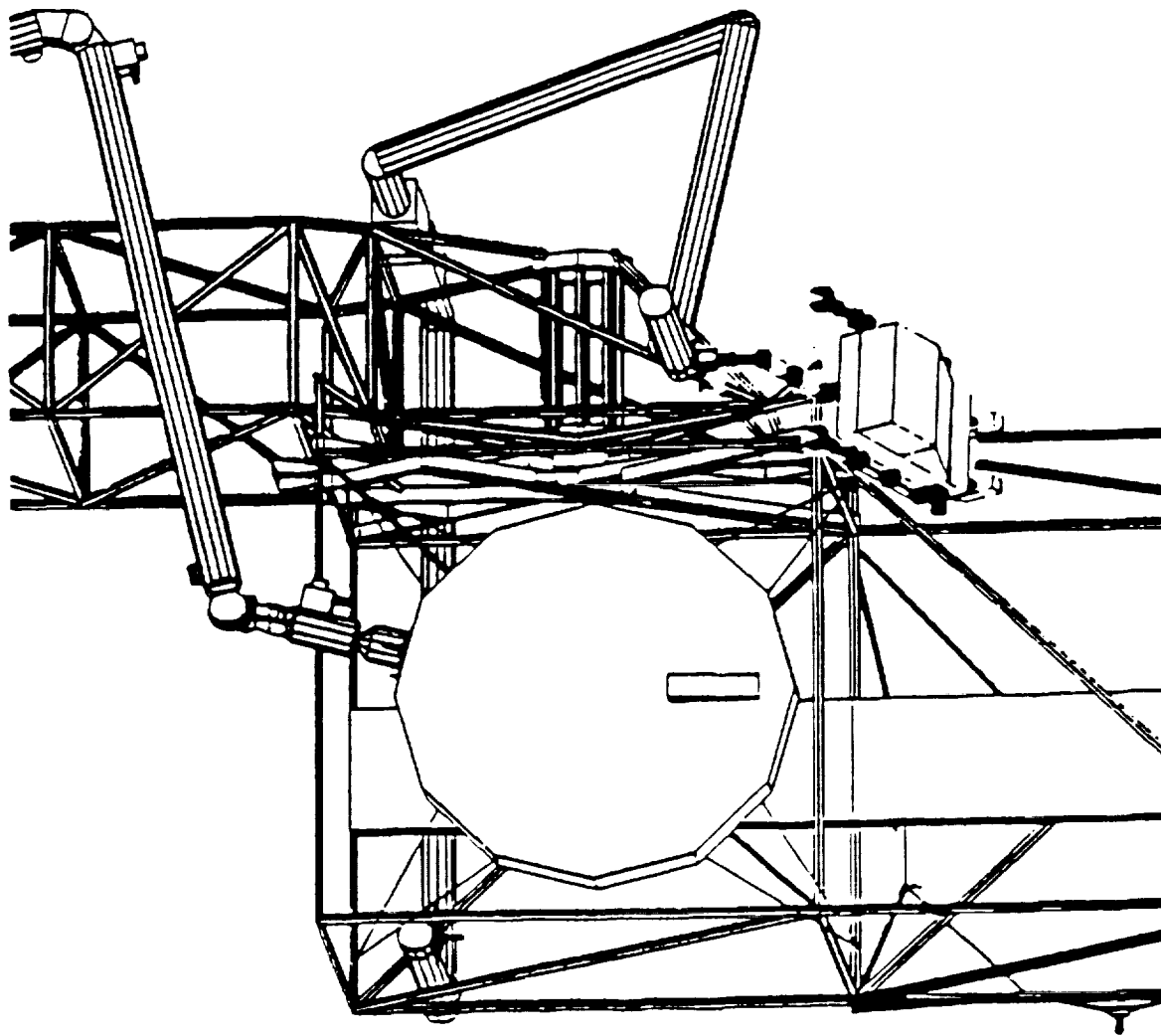


Figure B6. The FTS attached to the Astronaut Positioning System.

Space Station Freedom Interfaces

The SSFTS is designed to help in the assembly and maintenance of the Space Station Freedom (SSF) and as such needs to operate off both the Space Transportation System (STS) shuttle orbiter and SSF. Operations off of the STS will occur during the early SSF assembly flights and the SSFTS will make use of the standard STS interfaces, with perhaps the addition of a special umbilical for RMS operations. The SSFTS will require a workstation in the STS aft flight deck and interfaces to the STS power, data and video systems in the payload bay. The RMS will be employed to move and position the SSFTS for operations on the STS. This requires the SSFTS to be equipped with an RMS compatible grapple fixture for structural attachment to the RMS. As mentioned above, an umbilical may be needed to meet the SSFTS power, data and video requirements when operating from the RMS.

Once the SSF early assembly flights are completed the SSFTS will begin operating off the SSF. This requires SSFTS workstation interfaces with the SSF Multi-Purpose Applications Console (MPAC) and interfaces to the SSF Data Management System (DMS), Operations Management System (OMS), Communications and Tracking (C & T) and Electrical Power System (EPS).

The MPAC will serve as the SSFTS Workstation with the addition of SSFTS unique components. Presently, the FTS project intends to provide two 6 degree-of-freedom (DOF) force reflecting hand controllers, two standard data processors and an adjustable restraint system to augment the MPAC. The MPAC is also the SSFTS interface to the OMS.

Other SSFTS interfaces fall into the areas of transportation, resources and storage. The SSFTS is designed to be transported by and operated from the Space Station Remote Manipulator System (SSRMS) and will meet the SSRMS mechanical, power, data and video interfaces. The same grapple fixture on the SSFTS used for attachment to the RMS will be employed for attachment to the SSRMS. The SSFTS is compatible with the SSF 120 VDC EPS, Ku-Band C & T and DMS systems. Operations away for the SSRMS are possible in two basic modes. The first is the fixed-base dependent mode and requires a worksite attachment fixture that provides mechanical, power and data interfaces to the SSFTS. The second mode is the fixed-base independent mode and only requires a mechanical interface for attachment and stabilization. In this

mode the SSFTS receives power from its own battery and data through the SSF C & T system.

Additionally, the SSFTS requires storage accommodation on the SSF. This includes power for battery charging and checkout, data for health and status monitoring, mechanical attachment and storage for associated equipment and spares.

The SSFTS is also designed for Intra-Vehicular Activity (IVA) maintenance. This limits the maximum size of the SSFTS so that it can be passed through a space station hatch.

Summary

The Martin Marietta design for NASA's Flight Telerobotic Servicer meets the requirements set forth in the FTS requirements document and ensures that this country will benefit from an enhanced robotics program as part of Space Station Freedom.

The design incorporates such features as dual-arm cooperation, multiple light sources, force/torque and position sensors, and redundant manipulators. The telerobotic system will be operated via a teleoperated control station featuring man in the loop with two-arm bilateral force and position control, color video, and voice understanding/synthesis.

The Flight Telerobotic Servicer will evolve to include such things as stereo cameras, increasing autonomy, supervisory and automated planning as well as on-line task planning.

The project is planning two shuttle test flights to develop and demonstrate the FTS capabilities: the Development Test Flight (DTF-1) which is manifested in 1991 and the Demonstration Test Flight (DTF-2) in 1993. The space station FTS (SSFTS) is presently manifested for launch on the second element launch of Space Station Freedom (MB-2) to assist in the assembly of the space station. The contract schedule supports these activities and work is underway at Martin Marietta to meet these launch dates.

The FTS shall have the capability of being used on the shuttle Remote Manipulator System (RMS), with the space station Mobile Servicing Center (MSC), and as a smart front end on the Orbital Maneuvering Vehicle (OMV) to perform servicing tasks on free-flying spacecraft.

The FTS promises to be a safe, reliable and useful tool for the astronauts in performing assembly, maintenance, servicing and inspection tasks on the space station and from the shuttle and OMV. The FTS will be the basis for design standards for

future NASA payloads that require space-based servicing. Work is already underway to define and document these design standards and to work the interfaces with the future users of the FTS.

APPENDIX C

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APPENDIX D

Acronyms

A & R	Automation and Robotics
APAE	Attached Payload Accommodation Equipment
ARC	Ames Research Center
ART	Automated Reasoning Tool
ASPS	Attachment, Stabilizing, and Positioning Subsystem
ATAC	Advanced Technology Advisory Committee
C & T	Communication and Tracking
CLIPS	C-Language Production System
Code R	Code for the Office of Aeronautics and Space Technology
DKC	Design Knowledge Capture
DMS	Data Management System
DTF 1	Development Test Flight (first FTS flight test)
DTF 2	Demonstration Test Flight (second FTS flight test)
DTLCC	Design to Life-cycle Costs
ECLSS	Environmental Life Support System
EVA	Extravehicular Activity
FDIR	Fault Detection, Isolation, and Recovery
FEL	First Element Launch
FTS	Flight Telerobotic Servicer
GSFC	Goddard Space Flight Center
IVA	Intravehicular Activity
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LaRC	Langley Research Center
LeRC	Lewis Research Center
MPAC	Multipurpose Application Console
MSFC	Marshall Space Flight Center
MUT	Mission Utilization Team
NASA	National Aeronautics and Space Administration
NSTS	National Space Transportation System
OMA	Operations Management Application

OMGA	Operations Management Ground Application
OMS	Operations Management System
ORU	Orbital Replacement Unit
OSS	Office of Space Station Freedom
PDRD	Program Definition and Requirements Document
PMAD	Power Management and Distribution
PMS	Platform Management System
PRD	Program Requirements Document
SE & I	Systems Engineering and Integration
SIA	Station Interface Adapter
SPDM	Special Purpose Dextrous Manipulator
SSF	Space Station Freedom
SSFP	Space Station Freedom Program
TMIS	Technical and Management Information System
WP	Work Package



Report Documentation Page

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16. Abstract In April 1985, as required by Public Law 98-371, the NASA Advanced Technology Advisory Committee (ATAC) reported to Congress the results of its studies on advanced automation and robotics technology for use on the Space Station Freedom. This material was documented in the initial report (NASA Technical Memorandum 87566). A further requirement of the law was that ATAC follow NASA's progress in this area and report to Congress semiannually. This report is the ninth in a series of progress updates and covers the period between February 24, 1989, and July 12, 1989. NASA has accepted the basic recommendations of ATAC for its Space Station Freedom efforts. ATAC and NASA agree that the thrust of Congress is to build an advanced automation and robotics technology base that will support an evolutionary Space Station program and serve as a highly visible stimulator, affecting the U.S. long-term economy. The progress report identifies the work of NASA and the Freedom contractors, e.g., Work Packages, as well as the Flight Telerobotic Servicer. It also describes research in progress, and it makes assessments of the advancement of automation and robotics technology on the Space Station Freedom. <i>is ident. edo</i> <i>is also described</i> <i>are given.</i>			
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APPENDIX E

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